International Conference for
Sustainable Design of the
Built Environment
SDBE 2018
Proceedings

Editors
Heba Elsharkawy
Sahar Zahiri
Jack Clough
Foreword

The International Conference for Sustainable Design of the Built Environment SDBE 2018 forms one of the key deliverables of the British Council Newton Institutional Links Fund project: Building Capacity for Sustainable Development of the Built Environment (BC-SDBE) launched in April 2016. The aim of the BC-SDBE institutional link project is to bridge the gap between the rapidly developing advancements in research and training in sustainable development of the built environment globally, and the demanding professional development required in the construction labour market. The main objective of BC-SDBE project is to build capacity in education, research, innovation, and exploitation of state-of-the art sustainable development strategies to help promote and sustain socio-economic growth in Egypt.

Following the great success of SDBE 2017 conference where 112 papers were published in the proceedings, SDBE 2018 conference offers yet, another unique opportunity for academics, researchers, architects, urban designers, engineers, and professionals to meet and share the latest knowledge, research and innovations on low carbon building design, building performance, simulation tools and energy efficient building-related technologies. The conference theme is ‘Research in Practice’ where the focus is on showcasing sustainable design, building energy performance, sustainable planning of neighbourhoods and cities, emphasising a balanced approach to environmental, socio-economic and technical aspects of sustainability in practice based on research.

The book of abstracts includes all 110 accepted papers under 12 themes clustered into 6 thematic groupings. The full conference proceedings are available to download at http://newton-sdbe.uk/conferences/sdbe-2018/

On behalf of the SDBE 2018 Organising Committee, I hope the research papers hereby presented help stimulate further ideas for research in the near future.

Yours sincerely,

Heba Elsharkawy

BC-SDBE Principal Investigator
Keynote Speakers

Philip Jones, Professor, Welsh School of Architecture, Cardiff University

Phil Jones is Professor of Architectural Science at the Welsh School of Architecture, Cardiff University, where he currently co-directs the University’s Energy Systems Research Institute. His research area is in low energy, low carbon, and sustainable design in the built environment. He currently directs the Low Carbon Built Environment Project, including ten demonstrations of energy positive buildings and low carbon retrofits. He chairs the Welsh Government’s Building Regulation Advisory Committee. He chairs the Board of Directors of Warm Wales, a community interest company which helps to mitigate fuel poverty in Wales. He has chaired two European COST Action networks, Low Carbon Urban Built Environments (2005-2009), and Smart Energy Regions (2012-2016). He is Master Academic Adviser on Tianjin University’s Low Carbon Buildings ‘111’ project (2014-2018). From 2015 to 2017 he was Distinguished Visiting Research Professor at University of Hong Kong and continues to collaborate with their Sustainable High-Density Cities Laboratory.

Ashraf Salama, Professor, Head of Department of Architecture, University of Strathclyde

Ashraf M. Salama is Chair in Architecture and Head of the Department of Architecture at the University of Strathclyde Glasgow, UK. He has led three schools of architecture over the past 25 years in Egypt, Qatar, and the United Kingdom. He is a licensed architect in Egypt and was the Director of Research and Consulting at Adams Group Architects, Charlotte, North Carolina. Prof. Salama is the Chief Editor of ArchNet-IJAR, collaborating editor of Open House International, and editorial board member for numerous international journals. He also serves on the scientific and review boards of several international organizations in North America, Europe, and South East Asia. Professor Salama is the recipient of the 2017 UIA Jean Tschumi Prize for Excellence in the Architectural Education and Criticism. Professor Salama has published 9 books and over 170 articles and book chapters. His research interests and involve theories and methodologies of design studio teaching in architecture and urbanism; learning environments and workplaces; users-centred assessment of designed environments; adaptive urbanism and the spatial practice of migrant communities; liveability and diversity in rapidly growing contexts. He established and is currently leading the efforts CRAUCGS-Cluster for Research on Architecture and Urbanism of Cities in the Global South.
Patrik Schumacher, Director, Zaha Hadid Architects

Patrik Schumacher is principal of Zaha Hadid Architects and is leading the firm since Zaha Hadid’s passing in March 2016. He joined Zaha Hadid in 1988 and was seminal in developing Zaha Hadid Architects to become a 400 strong global architecture and design brand. He has been a partner since 2003 and a co-author on all projects. In 2010 Patrik Schumacher won the Royal Institute of British Architects’ Stirling Prize for excellence in architecture together with Zaha Hadid, for MAXXI, the National Italian Museum for Art and Architecture of the 21st century in Rome. He is an academician of the Berlin Academy of Arts. In 1996 he founded the Design Research Laboratory at the Architectural Association in London where he continues to teach. Patrik Schumacher is lecturing worldwide and is currently a guest professor at Harvard’s GSD. Over the last 20 years he has contributed over 100 articles to architectural journals and anthologies. In 2008 he coined the phrase Parametricism and has since published a series of manifestos promoting Parametricism as the new epochal style for the 21st century. In 2010/2012 he published his two-volume theoretical opus magnum “The Autopoiesis of Architecture”. Patrik Schumacher is widely recognized as one of the most prominent thought leaders within the fields of architecture, urbanism and design.

Sean Smith, Professor, Director of the Institute for Sustainable Construction, Edinburgh Napier University

Sean leads the Institute for Sustainable Construction, the CIAT Centre of Excellence in Architectural Technology and is Professor of Construction Innovation at Edinburgh Napier University. He has been an invited guest scientist in government construction research institutes in Canada, Italy and Germany. In 2009 and 2015 his research teams were awarded the Queen’s Anniversary Prize for the positive impact of their work for industry, environment and society for the ‘development of Robust Details’ and ‘Timber engineering and sustainable construction’. Over 1 million new homes across the UK have used his technical designs. He has supported over 80 low carbon innovative construction products to market, co-inventor of 17 patented products and led the formation of the Construction Scotland Innovation Centre. He currently chairs the Scottish Government working group for new housing construction skills.
Mina Hasman, Associate Director – Skidmore Owings & Merrill LLP (SOM)

Mina Hasman leads Skidmore Owings and Merrill’s sustainability and wellness operations and long-term vision, for the London office. She challenges existing best-practices by developing new systematic and design-based approaches applied and tested in complex, international projects.
Mina embraces multi-disciplinary research and collaboration with others to deliver sustainable design solutions that yield long-term environmental, societal and cost benefits.

Mark Jenkinson, Head of AMO Cities & City Director London Siemens Global Center of Competence Cities, Sustainability and Cities.

Based out of Siemens’ Global Centre of Competence for Cities at one of the world’s most sustainable buildings, the Crystal in the east of London, Mark oversees Siemens’ account management approach to cities world-wide.
In March 2013, Mark also took on the role of City Director for London – a key focus of the role is to support London’s sustainable development through the provision of smart, efficient technological solutions and services for building, energy and transport infrastructure.
Mark joined Siemens in 1993 and since then has taken on a variety of roles and responsibilities across Siemens in a wide range of industries and markets in the UK, across mainland Europe, the Middle East and Asia. Mark has participates in a number of committees including the Royal Docks Advisory Board and sits on UEL Industry Advisory Board for Civil Engineering.
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# Chapter One

## Building Performance Simulation, Building Performance Evaluation and Optimisation, and Building Information Modelling (BIM)

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**Education for Sustainability**

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**Chapter Three**

Energy Efficiency in Buildings, Environmental Design Strategies in Practice, and Low and Zero Carbon Design

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**Chapter Four**

Sustainable Construction Technologies, Resource Efficiency, and Renewable Energy and Green Technologies

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Chapter One: Building Performance Simulation, Building Performance Evaluation (BPE) & Building Information Modelling (BIM)
Assessing the Thermal Performance of Concrete-based Construction Systems in Hot Climates

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Abstract: The aim of this study is to evaluate the thermal performance of different types of concrete-based construction systems under the Egyptian climatic conditions. The study examines the thermal performance of a case study of reference roof-top space with an area of 144 square meters (12*12m) situated in a hot-temperate climate (Cairo, Egypt). It represents the evaluation of using typical construction system (solid slab) compared to flat plate, wide module and Slab and beam systems in a widely used concrete formwork construction systems in typical practice in Egypt. Dynamic thermal parameters including thermal admittance and window to wall ratio beside the thermal resistance and its reciprocal (U-value) were used in this evaluation. Different types of construction systems were simulated using the dynamic thermal simulation software Design-Builder to investigate their thermal performance upon roof-top space, in addition to estimate costs and saving benefits of each system. The purpose of this study is to demonstrate the potentials of these construction systems from environmental and financial viability standpoints to enable appropriate solutions to be chosen at the early stages of a design. The results of the study suggest that applying wide module system (so-called hollow blocks slabs) with inner columns to decrease loads and span of the slab can be considered as a favourable scenario, and can be a better choice for architects and structural engineers in designing buildings for hot climates.

Keywords: Thermal performance, construction systems, concrete-based slabs, thermal simulation, hot climates.

Introduction

Systems selection occupies much of a structural engineer’s time during the conceptual phase of a building, and many factors affect the decision to use one type of construction over another. Architectural design requirements, desired floor-to-floor heights, internal span of the spaces, external treatments, local contractors’ preferences, material costs, and aesthetics all influence the selection of structural components. When it comes to delivering value, selecting the right structural system is critical to building’s success. On the one hand, concrete has been used widely in the typical practice of construction rather than steel, especially in residential sector in Egypt. This was due to many factors, such as the price, easy of moulding and operation quality. On the other hand, concrete is not always the right choice of structural systems in hot climates but when it is, it can significantly reduce initial costs and provide high quality and high performance structure that will last many years with little maintenance. Concrete structural systems often exhibit unfavourable thermal characteristics including higher interior temperature, especially when active mechanical cooling is absence. This fact is often neglected or underestimated at the design stage. The high temperature coupled with using traditional reinforced concrete slabs which is characterized as poorly-insulated roofing system can cause a discomfort state among building users’.

Due to the high intensity levels of solar radiation, spaces underneath roof received the highest amount of heat gain through building fabrics, despite the fact that people in hot climates tend to install thermal insulation in roofs to overcome such problem. Heat gain to a building through its roof make up a large fraction of the cooling load. The cooling load is defined as the net rate of heat that must be removed from a space to keep it within comfort range (Yumrutaş et al, 2007). Therefore, much more attention will be given in this study to roof-top spaces in buildings located in hot-temperate climate like Cairo.
The key research question of this study asks, does the selection of concrete-based construction system have a significant thermal potential in reducing internal heat gains through building fabric. The main purpose of this study is to investigate the potentials of installing different types of concrete-based construction systems in the roof of the buildings in hot climates, and how they exhibit under the Egyptian climatic conditions. This study expands existing knowledge of the thermal performance of concrete-based construction systems in Egypt and other construction building systems in similar climates where buildings are exposed to high intensity levels of solar radiation, so that architects, designers and engineers can be given sustainable design guidelines to enable appropriate solutions to be chosen at the early stages of design to achieve low energy thermal comfort.

What on earth
Concrete-based construction has been known since early times. The invention of reinforced concrete increased the significance and use of concrete in the construction industry to a great extent. Architects and designers were driven by moldability characterises of concrete and its natural fireproof property to utilize the reinforced concrete to shape buildings in so many different and elegant forms (Gunel et al, 2007). The structural design of buildings is traditionally limited to material specification and structural efficiency. The modern innovative structural design tends to provide a framework to integrate the long-term of behaviour of materials and systems into initial design process. Modern integrated structural design keeps into account many factors such as building thermal performance and life cycle assessment tools to determine the environmental performance of building design to promote a more efficient use of materials and energy (Robati et al, 2017).

From environmentally stand point, one can finds that the wrong selection of building elements causes serious problems connected with economy, construction functionality and appearance, which will not be easy to correct and might has a negative impact on built environment (Alibaba et al, 2004). Every building deserves a thorough analysis including ancillary items affected by each different structural system such as the reduction in energy, skin and fireproof costs experienced with a concrete-based construction system.

Flat reinforced concrete roofs constitute the vast majority of urban mass of residential buildings in many regions over the world such as Middle East and particularly in Cairo. Materials availability, tradition of structural and architectural designs merged with the available building technology are the main reasons of using reinforced concrete-based construction in typical practice in Egypt. There are a number of viable concrete structural systems to consider when looking at concrete-based construction systems. All these systems share the benefits provided by concrete as a material but each has nuances that can help to achieve the specific functionally goals of the building.

A vast range of concrete-based systems are used in construction in Egypt. Solid slab structural system is most economical, it accommodates bay sizes up to 6*6m and generally used for multi-unit residential buildings. Flat plate structural system is very similar to solid slab but it accommodates bay sizes up 9*9m and often post-tensioned. The bay sizes can be increased to 10*10m with drops. Wide Module structural system (so-called Hollow blocks) is usually a mild-reinforced moment frame that can accommodate bay sizes up to 13*13m. It is suitable for heavy loading with minimal deflection and widely utilized for office, healthcare, classroom and laboratory. Slab and beam structural system (so-called Panelled beam) is suitable for large bays or isolated conditions but not economical for reuse on larger multi-story structures.
One of the most defects of concrete is its low thermal resistance that lead to an increase in internal temperature of the buildings over the most of the year, and consequently an increase in energy consumption due to air-conditioning purposes (Najim et al, 2015). Concrete is a high thermal mass material that could minimize heat fluctuation as it has ability to absorb heat and keep it during daytime and then gradually release it during night (Harris-Bass, 1982). Taking into account the thickness of reinforced slab could vary from 120-400 mm thick according to the selection of structural system, a key consideration would be the roof structural system through which a large amount of heat is absorbed during day time, stored inside the envelope’s thermal mass and then released during the night when the outdoor temperature becomes lower. Broadly speaking, Roofs represent around 50% ±10% of the total exposed surfaces area to the weather, and around 60-70% of the total gained heat comes from building’s roof and its external walls in hot climates (Brito Filho, 2014). Investigating the thermal performance of concrete-based structures of roof top spaces could highly contribute in reducing energy consumption and maintain internal temperature within comfort range in hot climate regions.

**Design parameters and methodology**

**Overview**

Much of the current literature on thermal performance of buildings pays particular attention to evaluation of building’s envelope and building’s roof. Some previous studies focused on the effect of insulation and roof covering on the thermal performance (D’Orazio et al, 2010) while others investigated different thermal performance parameters for air-conditioned and non-air-conditioned buildings (Barrios et al, 2011) (Barrios et al, 2012). Becerra-Snatacruz et al. (2016) examined the thermal performance of a case study of low-income housing using concrete formwork construction system situated in a warm- temperate climate. Results revealed poor thermal performance with houses falling significantly outside the thermal comfort boundaries due to a number of factors including thermal properties of building envelope and the impact of solar radiation. Findings demonstrates the urgency of designing viable solutions according to local climates.

Sang-Hoon et al. (2017) provided in-depth analysis the thermal mass effect of reinforced concrete beams with structurally optimized geometrical forms. The relation between the thermal mass, the implication on thermal comfort and the given geometrical parameters of exposed reinforced concrete beams are explored. Najim et al. (2015) evaluated the existing concrete-based roof of residential buildings in Iraq. Found that using light-weight precast rubberized concrete instead of conventional concrete ones has no significant influence regarding thermal performance. Using false ceiling with appropriate air-gap between as-build reinforced concrete slab and finishing boards is the most effective way in improving thermal performance of the concrete-based roofs. From the same standpoint, Tong et al. (2014) predicted the transient roof temperature and transmitted heat flux through multilayer roofs of naturally ventilated rooms. A field experiment was carried out and a parametric study was conducted to investigate the impacts of roof-top surface solar reflectivity and thermal resistance on the thermal performance of two types of concrete-based roof, found that compared to the roofs with solar reflectivity of 0.1, increasing the solar reflectivity by 0.1 reduces the daily heat gain by 11% in both the unventilated and ventilated roofs during a typical weather day in Singapore. Korniyenko (2015) investigated the thermal performance of residential building envelope by using two methods; the visual-instrumental...
inspection and numerical model of heat transfer. The integrated application of these methods gave an opportunity to determine the thermo-technical state and latent defects of building’s envelope. Robati et al. (2017) highlighted that selecting an appropriate method for concrete-based construction and form could affect the total energy performance and thermal comfort of a building, a fact that is often overlooked by design team through the initial phase of building’s design.

**Study model**

A case study approach was used to assess the thermal performance of concrete-based construction systems, a room with an area of 144 square meters (12*12m) has been used as reference case to be examined under the Egyptian climatic conditions. As shown in Figures 1 and 2, the room has two windows in the southern façade, with an area of 2.7 square meters (1.2*2.25m) each. Southern orientation of the building has been chosen since they receive large amounts of heat gain. Room’s clear height is 3m. Windows are aluminium frames held 6 mm single clear layer glazing with solar heat gain factor (SHGC) of 0.8, and the window-to-wall ratio was 15%. All building construction materials used in typical practice in Egypt were applied; exterior walls are made of 250 mm red brick with an exterior finish of 30 mm thermal plaster and 20 mm external rendering and a 25 mm thickness of cement plaster and paint for the interior finish.

Figure 1. Reference case plan.
Figure 2. Reference case model in Design-Builder.

Slabs are made from reinforced concrete with 140 to 370 mm thick according to the structural system. Roof is flat and insulated with 70 mm of thermal insulation and 10 mm damp proof. Figure 3 illustrates typical reinforced concrete roof in Egypt. Different types of concrete-based construction were applied in the comparative study including solid slab, flat plate and wide module structural systems, in addition to slab and beam structural system. Thermal transmittance (U-Value) of different concrete-based slabs was calculated as shown in Table 1, insulation was neutralized as it is vary according to type, price and thickness.

Figure 3. Reinforced concrete-based roof (Typical practice in Egypt).

Table 1. Thermal transmittance of different concrete slabs (without insulation).

<table>
<thead>
<tr>
<th>System Description</th>
<th>Solid slab system with inner column</th>
<th>Flat slab system with inner column</th>
<th>Wide module system without inner column</th>
<th>Wide module system with inner column</th>
<th>Slab and beam system</th>
</tr>
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<tr>
<td>U-value (W/m².K)</td>
<td>3.72</td>
<td>3.36</td>
<td>2.47</td>
<td>3</td>
<td>4.17</td>
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</table>
Calculations and simulation

A parametric study was carried out using some 3D models of the room described earlier based on four different scenarios with different construction systems. All scenarios were applied and compared against the reference room model. Based on calculations and type of structure, the reference room model (Base case) applied a solid slab with inner column in the centre of the room, and 180 mm thick. The first scenario (S1) applied flat plate system with inner column in the centre of the room, and 220 mm thick. The second scenario (S2) applied wide module as a structural system for the slab with a thickness of 370 mm, and free space without any inner column in the centre of the room. The third scenario (S3) almost the same as the second one but the thickness of the wide module slab was 270 mm with inner column in the centre of the room. The forth scenario (S4) applied Slab and beam structural system with 140 mm slab thickness and no column in the centre of the room. The gross, net concrete quantity and reinforcement ratio have been calculated, in addition to safety for lateral loads and concrete compressive strength (Fcu). Table 2 summarized the description of all scenarios while Table 3 summarized calculations of concrete price, costs and savings in (EGP).

The simulation package being used in this study was Design-Build version 4.5. It uses as its calculation engine Energy plus 8.3, a powerful thermal simulation package developed by the US Department of Energy. A series of simulations were performed based on a real weather data file for Cairo (ETMY). The summer typical week of the year which represents the summer season was selected, i.e. the summer typical week which lasts in Egypt from 5th of July to 11th of July.

Table 2. Description of different scenarios.

<table>
<thead>
<tr>
<th>System Description</th>
<th>Base Case</th>
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<th>S2</th>
<th>S3</th>
<th>S4</th>
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<tr>
<td>Solid slab system with inner column</td>
<td>Flat plate system with inner column</td>
<td>Wide module system without inner column</td>
<td>Wide module system with inner column</td>
<td>Slab and beam system</td>
<td></td>
</tr>
<tr>
<td>Area net (m²)</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
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<tr>
<td>Thickness (cm)</td>
<td>18</td>
<td>22</td>
<td>37</td>
<td>27</td>
<td>14</td>
</tr>
<tr>
<td>Average Thickness (cm)</td>
<td>24.50</td>
<td>25.87</td>
<td>30.63</td>
<td>18.94</td>
<td>26.67</td>
</tr>
<tr>
<td>Concrete Quantity Gross (m³)</td>
<td>37.00</td>
<td>38.75</td>
<td>55.50</td>
<td>40.50</td>
<td>40.20</td>
</tr>
<tr>
<td>Concrete Quantity Net (m³)</td>
<td>37.00</td>
<td>38.75</td>
<td>42.00</td>
<td>28.42</td>
<td>40.20</td>
</tr>
<tr>
<td>Average Foam Thickness (cm)</td>
<td>-----</td>
<td>------</td>
<td>0.12</td>
<td>0.11</td>
<td>-----</td>
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<tr>
<td>Reinforcement Ratio</td>
<td>100 kg/ m³</td>
<td>115 kg/ m³</td>
<td>180 kg/ m³</td>
<td>130 kg/ m³</td>
<td>120 kg/ m³</td>
</tr>
<tr>
<td>Safety for Lateral Loads</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Very Good</td>
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As Shown in Figure 4, all scenarios shown previously in Table 1 were applied. All building materials described previously were applied into the models. Simulations were undertaken in free running mode without any heating or cooling systems operating. 25 days were used as a maximum warm-up period (pre-conditioned) to ensure correct distribution of heat in building thermal mass before the start of the simulation.

**Table 3. Workmanship price, Costs and savings in (EGP).**

<table>
<thead>
<tr>
<th>System Description</th>
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<th>S3</th>
<th>S4</th>
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<tr>
<td>Solid slab system with inner column</td>
<td>300</td>
<td>280</td>
<td>300</td>
<td>280</td>
<td>350</td>
</tr>
<tr>
<td>Flat plate system with inner column</td>
<td>680 LE Fcu= 250</td>
<td>680 LE Fcu= 250</td>
<td>750 LE Fcu= 300</td>
<td>680 LE Fcu= 250</td>
<td>750 LE Fcu= 300</td>
</tr>
<tr>
<td>Wide module system without inner column</td>
<td>2230</td>
<td>2400</td>
<td>3300</td>
<td>2685</td>
<td>2600</td>
</tr>
<tr>
<td>Wide module system with inner column</td>
<td>82500</td>
<td>93000</td>
<td>156600</td>
<td>90200</td>
<td>104520</td>
</tr>
<tr>
<td>Slab and beam system</td>
<td>-----</td>
<td>11.3%</td>
<td>47.3%</td>
<td>8.5%</td>
<td>21%</td>
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</table>

**Results and discussion**

The base case and four different scenarios were simulated and temperature profile of the typical summer week of each was analysed. It was decided to select the day of 5th July as typical summer day. As shown in Figure 5, the operative temperature profile of reference case was compared against other four different scenarios; flat plate system (S1), wide module
system without central inner column (S2), wide module system with central inner column (S3) and Slab and beam system (S4) respectively. Findings show that maximum heat gain occurred at (2:00 pm) and the minimum was at (6:00 am). Results confirm that during the minimum heat gain period around (6:00 am), wide module system without column exhibited the highest temperature while Slab and beam system exhibited the lowest. During the peak period of the day around (4:00 pm), wide module system with inner column exhibited the highest temperature while Slab and beam system was the lowest.

Figure 5. Temperature profile of all scenarios compared to (Base case).

Applying S1, S2 and S3 reduces the peak internal temperature by approximately 0.3, 0.5 and 1.2 °C respectively. It might be a slight reduction in the peak internal temperature, but when the internal temperature was analysed during a period of time like the whole day or night time period, referring to reduction ratio might help to figure out the significance value. Applying S2 and S3 can reduce the average temperature by approximately 0.5 and 1.2% during the whole day compared to reference case. A reduction by approximately 0.8, 1.3, 2.2% noticed when S1, S2 and S3 respectively were applied during the peak period that lasts from (2:00 pm) to (7:00 pm), while an increase in average temperature noticed by applying S4 during the same period. During daytime that lasts from (6:00 am) to (1:00 pm) applying S4 fulfilled the lowest reduction in average temperature by approximately 0.8% compared to reference case, while applying S1, S2 and S3 can lead to an increase in average temperature by approximately 0.1, 0.5 and 0.5% respectively. During night-time lasts from (8:00 pm) to (12:00 pm), applying S2 and S3 can reduce the average temperature by approximately 1.2, 2.4% respectively, while an increase in the average temperature by approximately 0.5% noticed when S4 was applied in the same period. Figure 6 shows a comparison of reduction in temperature of all scenarios against reference case.
The results of temperature profile of all scenarios suggest that the application of wide module system with inner column in the centre of the room results in a significant reduction in internal temperature during peak hours and night-time period. Using wide module system (hollow blocks slab) helps in reducing internal temperature as foam blocks (insulation materials) are being used to fill the gaps between rips in this type of structural system (typical practice). Increasing thermal insulation by using foam blocks can be counted as add value to this type of structure. Also, adding column in the centre of the room eliminates loads and the thickness of the slab and consequently the cost of structural system. Results confirm that applying the third scenario (S3) fulfilled the heights reduction in terms of internal temperature.

Figure 6. Comparison of reduction in temperature of all scenarios of all scenarios compared to (Base case).

Figure 7. Increment of the total cost of structure of all scenarios.
As Table 3 shows the price of concrete, workmanship and total cost of reinforced concrete. One can find that solid slab (Base case) represents the lowest cost among all other types of structures. Also, it has many other advantages like earthquakes resistance (Safety for lateral loads), and concrete net quantity as shown in Table 2. Flat plate and wide module systems have a poor response while Slab and beam system has a very good response in terms of earthquakes resistance compared to reference case. Wide module system with central inner column has a lower value in terms of the net concrete quantity compared to reference case. Moreover, its average thickness exhibits the lowest among all other types of structure. Wide module system with central inner column and flat plate system are cheapest in terms of workmanship. Also, concrete price of wide module system with central inner column is almost the same as solid slab (Base case).

As shown in Figure 7, Applying S1, S2, S3 and S4 can lead to an increase in the total cost of the structure by approximately 11, 47, 9 and 21% respectively. Applying wide module system with inner column (S3) exhibits the lowest increase by approximately 9%. A comparison of the two results of thermal performance and cost reveals that by applying the third scenario, a significant impact in reducing the internal temperature in peak hours and night-time compared to reference case. This can be applied with slight increase in the cost of construction by approximately 9% of the total cost of the reference case. It is clearly that using wide module system (hollow blocks slab) associated with inner columns to reduce the span and loads is the most effective way in improving thermal performance of the concrete-based construction according to typical practice and Egyptian climatic conditions. This can be considered as a passive technique to improve thermal performance of roof-top spaces in hot climates.

Conclusion

This study examined the impact of applying different types of concrete-based construction to improve the thermal performance of the roof-top spaces to be applied in hot climate regions. Applying wide module system (so-called hollow blocks slabs) with inner columns to decrease loads and span of the slab can be considered as a favourable scenario, as it decreases the internal temperature of room space by approximately 2.2 and 2.4% during peak hours and night-time hours respectively. Although using wide module system is slightly more expensive than solid slab system by approximately 9%, it appears that thermal performance benefits can be considered in comparison with other types of structure. Wide module system can be considered as passive technique to reduce the internal temperature of Southern spaces as it received the highest amount of heat gain through daytime.

The present study makes several noteworthy contributes to the selection of appropriate structural system from environmental stand point. Further work needs to be done to determine the feasibility of applying the additional cost in construction compared to the installation cost of cooling equipment. The results of this study have gone some way towards enhancing sustainable building design by offering simple steps and methodological approach to be applied to new and existing buildings when renovated. These results confirm the view that the current practice of construction in Egypt needs to include the integration of building thermal simulation with other architectural and structural issues in the early design stage and consider passive cooling techniques rather than mechanical cooling, especially with the increase in energy prices and the abolition of subsidies expected through the near future.
Acknowledgments

The author warmly thanks Dr. Hamed Mowafy for his help and valuable contribution regarding all structural calculations and concrete price analysis according to Egyptian market and typical practice.

References


**Pathways to Building Performance Simulation through IFC and gbXML**

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**Abstract:** This study investigates pathways that can potentially link Building Information Models (BIM) to building performance simulation (BPS) models. It aims to create an interoperability guide for novice architects through a consistent unit-based model testing methodology. For this study, we used Autodesk Revit to create the BIM models. For BPS models, we used OpenStudio and DesignBuilder, both of which leverage EnergyPlus (EP) as a simulation engine. In the first part of the research, we investigated data translation using the Industry Foundation Classes (IFC) and the Green Building XML schema (gbXML). The results indicated that the pathway via IFC includes more intermediate steps but it concerns specific tested software and this conclusion cannot be generalized. Thus, the main study focused on software interoperability using the gbXML schema. We investigated eight unit-based models using a consistent testing pattern procedure. Interoperability issues were observed, classified and documented, mostly referring to missing data or geometry distortion. The paper concludes with a discussion of the impact of the identified limitations on the energy simulation field and a possible new research direction using non-manifold topology.

**Keywords:** Building Information Modeling, Building Performance Simulation, IFC, gbXML, EnergyPlus

**Introduction**

Over the past decades there has been a rising awareness about the crucial role of Building Performance Simulation (BPS) in the reduction of the overall energy consumption and the increase of energy efficiency of the buildings (Bazjanac et al 2011). Meanwhile, BPS has become a major requirement by mandatory government regulations and leading energy performance assessment systems (Kim & Anderson 2013). At the same time Building Information Modelling (BIM) is constantly gaining popularity among the Architecture, Engineering, and Construction (AEC) industry as it is an interoperable model, the benefits of which are most evident in model visualization, cost estimate and collaboration amongst stakeholders, designers and contractors (Volk et al 2014).

The importance and the reasons why BIM and BPS models should be integrated in a unified procedure have been widely stated in the literature, not only by researchers but also by construction practitioners (Becerik & Kensek 2010). One of these reasons is the high percentage of time consumed in adjusting/rebuilding the initial BIM model in energy simulation software due to gaps in linking BIM and BPS (Figure 1). This percentage is estimated to reach almost 80% of the whole energy simulation procedure (Jiang et al 2012), due to limited connections between those two major fields of the design and construction industry. Moreover, narrowing the gap by improving interoperability between BIM and BPS means that energy modelling can also be incorporated in the early design stages, leading to more efficient and high-performance buildings (Kim & Anderson 2013). In order to achieve better interoperability, some efforts have been made in current design industry practice comprising two dominant data exchange formats: Industry Foundation Classes (IFC) and Green Building XML schema (gbXML), both being supported by BIM developers (Sanhudo et al 2018; Kim & Anderson 2013). Their capabilities and limitations in data exchange procedures between a BIM based model and a BPS tool, as shown in Figure 1 [after (Maile et al 2013)],
are investigated under the scope of the geometry conversion process. For this investigation, Architecture Revit 2015 was selected as the BIM platform and EnergyPlus (EP) as the simulation engine, both of which are compatible with the data exchange formats and commercially supported. However, EP does not have a Graphical User Interface (GUI), which is very important for the visual verification of results (Attia et al 2009). So, as far as the specification of the GUI is concerned, OpenStudio (OS) plugin for SketchUp and DesignBuilder (DB) were selected for this study as they are considered two of the most commercially supported and widely adopted tools in the energy simulation field leveraging EP.

![Diagram](image)

Figure 1. Generic geometry conversion process (created by authors).

There are two main aims of this study. The first is to indicate through which pathway and respective data exchange schema a more robust, simple and repeatable data translation is achieved; and the second is to add knowledge in the existing literature and create a pattern of testing methodology for future research studies. Therefore, this study comprises two parts according to the two main aims mentioned above. In the first part, a general comparison between IFC and gbXML, both in terms of literature review and in experimental terms, is conducted and in the second part, interoperability limitations for gbXML schema are investigated by implementing a specific pattern of testing methodology.

**Comparative analysis between IFC & gbXML**

**Comparison of characteristics between IFC and gbXML**

This section compares IFC and gbXML and reviews the relevant literature. From relevant studies, it is indicated that both have been developed to facilitate the interoperability of building information between an architectural and a BPS model (Moon et al 2011). However, the way they recognize and handle data is different (Hethrington et al 2011). This comparative analysis summarizes weaknesses and strengths of each schema in terms of field of applicability, structure and complexity as well as commercial support and compatibility with other programs. The most important difference between the two schemata is the philosophy according to which they have been developed. gbXML has been specifically developed for energy performance analysis, compared to IFC which is not specialized in a specific part but contains a large amount of data and enables data exchange in the philosophy of the whole building life cycle (Kim et al 2012), (Yu et al 2013). Technical structure/complexity: IFC can support any shape, since it is a more complex data representational schema, while gbXML only supports planar surfaces as far as geometry is concerned. Although IFC is supported by the majority of software companies it may lack proper implementation which leads to some inconsistencies (Eastman et al 2011).

**Experimental comparison between IFC and gbXML**

This section presents the testing procedure of the experimental comparison between IFC and gbXML. This procedure comprises a general test for each schema where the BIM based model is an architectural template project incorporated in Revit 2015, identical in both cases, and the GUI is OS. But, as the direct import of IFC in OS was not possible at the time of the writing, BIMserver was used as an intermediate step to translate the IFC file to a format compatible
with OS (.OSM file) and Solibri Model Checker (SMC) was the software used to visually check the exported IFC file from Revit, as Revit does not offer export dialogue for IFC files. So, the testing pathways are: Revit → gbXML → OS (Test A) and Revit → IFC → SMC → BIMserver → OS (Test B). The pathway: Revit → gbXML → DB (Test C) is also tested using DB as an alternative GUI. Test C is based only on gbXML schema as IFC is not compatible with DB. Tests A and B investigate which pathway offers a more complete and direct translation of data based on the criteria of robustness, simplicity and repeatability. Test C investigates whether different GUIs give different results when tested on a specific data translation schema (gbXML).

**Results and discussion**

Tests A & B: Firstly, IFC and gbXML files were exported from Revit model and then visually checked in SMC and Revit respectively (Figure 2). Then gbXML and IFC files are imported in OS (Figure 3).

The gbXML imported file in DB seems more complete than the IFC imported file in OS. In the latter case, none of the rooms are recognized since all the roofs are missing, leading to more primitive geometry interpretation, without however having specified whether this limitation is due to the IFC schema itself or due to the BIMserver software, due to time limitations. As far as robustness is concerned, the results indicate that the pathway through IFC and BIMserver gives a less complete thermal geometry model. In terms of simplicity, as IFC direct import is not supported in OS (or any other GUI leveraging EP), the intermediate step of BIMserver file translator is necessary in order to achieve IFC import in OS. This adds a level of complexity in the path through IFC and possibly BIMserver is the cause of the limited data translation from BIM to OS. This possibility derives from the fact that IFC has successfully translated the BIM geometry similarly to gbXML (Figure 2), therefore the cause of the final primitive model in OS lies at the last stage of data translation from IFC to OSM file through BIMserver. Finally, regarding repeatability, the IFC file was not translated into .OSM file through BIMserver with the first attempt and this procedure had to be repeated many times until a proper .OSM file translation was achieved.

Tests A & C: The comparison between two different GUI (DB & OS), based on the same schema (gbXML) gives the same results. Thus, concerning the two GUI (DB and OS) it becomes apparent that the GUI does not play a role in the data interoperability procedure.

As a general conclusion, it can be mentioned that gbXML leads to a more direct translation of a BIM-based design case into an energy simulation model. Although IFC seems to translate effectively the BIM geometry, it is however more complicated to reach the final step OSM translation. Some evidence indicate that this is due to the intermediate step of
BIMserver but a more in-depth investigation of the cause, as well as the full potentials of IFC, have not been examined in detail due to time limitations. Therefore, only gbXML schema was used for further investigation of detailed and specific interoperability limitations.

Interoperability limitations based on gbxml: research methodology statement

The second part of the experimental part of this study refers only to gbXML schema for the specific path from REVIT → gbXML → DB/EP.

Strategies of methodology implementation

The in-depth investigation of interoperability issues is based on a taxonomy of unit-based test models that applies a specific pattern in the testing procedure. The unit–based model testing methodology means that the testing is done for each element individually/separately. It encompasses the deconstruction of the complex project used in the previous chapter to its basic elements and the categorization of these elements by forming a Taxonomy of the test cases. The main aims of this methodology are:

- Gaining a deeper insight of each schema regarding interoperability limitations that are expected to be found in a real design project.
- Introducing a pattern of testing methodology that can be applied to future research concerning a similar path (eg: Revit → gbXML → IES) or cases that leverage IFC instead of gbXML.

Experimental comparison between IFC and gbXML

This section presents the testing procedure of the proper implementation which leads to some inconsistencies (Eastman et al 2011).

The taxonomy of unit-based model tests

Taxonomy refers to ‘the science or practice of classification’ (The American heritage 2011). Respectively, in the case of unit-based model testing the concept of taxonomy applies to the classification of the existing and the suggested cases according to specific guidelines for the taxonomy. The categorization of unit-based elements enables a systematic approach of recording the existing test cases and enables the user to detect and add more cases for further research. Moreover, the mapping of the existing cases indicates voids in literature so that new test cases can be easier spotted and suggested. The criteria that help the user identify cases for further research and suggest new test cases are analyzed in section later. Thus, an open–ended process is created, meaning that more cases can be added to this taxonomy diagram anytime by the user. A taxonomy of the specific existing and suggested test cases is also necessary in order for some of the gaps in the existing literature to be filled and arbitrary test suggestions to be avoided (Eastman et al 2011).

The taxonomy criteria

Since this experimental chapter refers to thermal analysis models and the gbXML schema, the guidelines for the taxonomy are formed by correlating the basic thermal modelling evaluation criteria, mentioned in existing research (Moon et al 2011) and the hierarchical order of the gbXML data structure. The model testing and the interoperability evaluation process include only the categories that are related to space and geometry as well as thermal properties interpretation. Consequently, the diagram of the guidelines for the taxonomy is narrowed down to the categories of spatial and geometry data interpretation, which are the color highlighted groups in Figure 4.
The pattern of testing procedure
The data interoperability investigation requires some steps in order to define the problem and search for a possible solution resembling the procedure of solving a problem in informatics similar to an algorithm (Chaudhuri 2005). However, as an algorithm can be too verbose a pictorial description of this procedure is necessary. This description is accomplished through program flowcharts, which are used to indicate the steps and demonstrate the logic structure of a program. This sequence of the steps followed when a problem is solved by a computer program are also applied to ordinary or more sophisticated problem solving and investigation procedures. Therefore, the concept of the flowchart is generalized and matched with the interoperability investigation procedure as shown in Figure 5. The input data corresponds to the unit-base test case, the flowchart diagram defines the procedure, namely the steps (and their respective relationship) that need to be followed for the problem investigation and the output of the flowchart is the conclusion concerning the extent of the interoperability limitation and whether a solution has been found.

Criteria for test results classification
The investigation of interoperability limitations focuses on three major considerations: Firstly, in how many cases a direct and correct translation in DB can be achieved, secondly the extent of the initial BIM model geometry distortion when imported to DB in the case of inaccurate data translation, and finally the specification of the interoperability limitations’ impact on the thermal analysis results. The ‘faulty’ gbXML imported model was compared with the ‘correct’ model, recreated or modified in DB representing the initial Revit case. Depending on the percentage of difference on the results between the two simulated models, the cases are classified to have a minor (difference < 10%) or major (difference > 10%) impact. Although no relevant acceptable percentage of error between simulations of a BIM based model and a
directly created model in the simulation software has been found, the above-mentioned percentage of 10% refers to calibration criteria (Robertson et al 2013) as feasible calibration solutions, adopting ASHRAE Guideline 14. Thus, it is used as an indication of acceptable Normalized Mean Bias Error (NMBE) of the simulation results between the ‘faulty’ and the ‘correct’ model.

Figure 5. Flowchart diagram of testing procedure (created by authors).

**Specification of suggested test cases**

The Taxonomy of the existing relevant cases indicates the amount of previously investigated cases regarding interoperability issues from Revit to DB or similar software through gbXML. It acts as a basis for the specification of the suggested new test cases or the cases for further research. For this purpose, the overview of each one of the existing cases has comprised two main steps: The brief description and analysis of the existing literature or test cases and the specification of cases for further research if necessary, along with comments on the estimated impact on thermal analysis in case of potential data interoperability limitations.

An existing case is suggested for further research when this case has not yet been tested for the path of this study: Revit $\rightarrow$ gbXML $\rightarrow$ DB or when the impact of test results on DB thermal analysis model is not mentioned in existing literature and needs to be clarified. Apart from cases for further research, there are also new cases for investigation, which are suggested when a test or a category of test cases have not been detected in the existing literature or when a test case concerns a higher level of complexity and a more advanced modelling case. Based on the taxonomy of existing relevant test cases and considering the cases of further research or the suggestion of new cases for investigation, the final taxonomy of suggested and selected test cases is formed and presented in Figure 6, indicating in which general category each case belongs. The final selected test cases are summarized below:
• **Zone modelling, zone/room merging (further research of existing case) - Test 1:** The case of the separation of a room with hanging partitions is investigated. ‘Hanging partitions’ are partitions that do not create zones because they do not connect at both ends with walls/partitions, but they are calculated by EP in the energy simulation process as thermal mass (DesignBuilder 2011). Therefore, in Revit three rooms are merged to one by making the separating walls ‘non-room bounding’ which corresponds to one zone with ‘hanging’ partitions in DB.

• **Zone modelling, room/zone separation line (further research of existing case) - Test 2:** A ‘virtual partition’ between two zones is used for separating perimeter zones from core zones when there is to be different HVAC provision or when carrying out daylighting or solar overheating studies involving high level of solar gain around the
perimeter. In the absence of ‘virtual partitions’, the risk of overheating could be underestimated due to the distribution of solar gain throughout the open plan space (DesignBuilder 2011). Room separation in Revit via ‘room separation line’ corresponds to ‘virtual partitions’ in DB. The interpretation of a room in Revit with two separation lines to a zone in DB with two virtual partitions is investigated.

- **Curved wall interpretation (new suggestion)-Test 3:** The case of a curved wall modelled in Revit and its actual interpretation in DB is investigated. This case concerns a higher level of geometry complexity.

- **Double curved wall interpretation (new suggestion)-Test 4:** A double curved wall, as an example of higher level of geometry complexity, is modelled in Revit and its actual interpretation in DB is investigated.

- **Curved curtain wall interpretation (new suggestion)-Test 5:** In Revit, a curtain element can be modelled based on two types of families: curtain wall or curtain system. The curtain element is modelled and investigated in both cases.

- **Interpretation of double height space/atrium (new suggestion)-Test 6:** An interior double height space with a gallery (slab projecting only from one wall) is modelled in Revit. The proper interpretation in DB, as one double height zone but with an intermediate horizontal separating slab (gallery), is investigated.

- **Thermal properties of vertical shading surfaces (further research of existing case)-Test 7:** Existing literature (Chan & Farrell 2015) mentions that thermal properties are supported by gbXML schema for the room bounding elements without clarifying about shading surfaces. Thermal properties are applied to vertical shading surfaces / elements in Revit and it is investigated whether they are considered in the calculations of the energy simulation analysis.

- **Thermal properties of horizontal shading surfaces (new suggestion)-Test 8:** Same as previous test, but with horizontal shading surfaces.

**Settings of thermal simulation analysis**

All the test simulations conducted in DB follow the same specifications: Simulation day: 10\(^{th}\) of June to include extreme cases in temperature and solar gains and indicate possible differences between the two simulated cases | HVAC system specification: Only natural ventilation ON, by value, 24 min temperature | Number of time steps: 4 | Simulation on an hourly basis | Air tightness: 0.7 ac/h | Schedules of occupancy & lighting set to ‘Office_OpenOff_Occ’ & ‘Office_OpenOff_Light’ in DB respectively.

**Test results and discussion**

Figure 7 summarizes the results of the unit-based model cases as well as the results of cases previously tested by authors. The latter are distinguished by the rest whilst the tests were conducted by the same authors of this paper. They are distinguished because they were conducted on a different period and were based on a methodology not so specifically defined as the current one. However, the inclusion of those cases in the overall study helps in the enrichment of the data and in the identification of a larger spectrum of potential interoperability limitations. Each case is categorized in CLASS A, B or C depending on the extent of data interoperability. In CLASS_A the data are translated in DB either directly or after specific modification of the Revit model. In CLASS_C the data are not translated properly in DB or are not translated at all and the case cannot be modified in DB neither.
For the cases that geometry distortion of the gbXML model was detected but modification of the model in DB is possible (CLASS_B) a further investigation of the impact of these misinterpretations on the thermal analysis results is conducted. A sub-categorization in CLASS_B_1 & B_2 is applied depending on percentage of difference in the results of thermal analysis between the model based on gbXMl and the model created directly in DB. The aspects discussed below include the extent of proper data interpretation in the DB import model for the three classes, the extent of model geometry Distortion and the subsequent level of manual modification needed in DB and finally, the impact of the geometry interoperability limitations on the thermal analysis results in DB.

**Data interpretation**

The majority of the tested cases have presented interoperability issues during their direct translation in DB and so the gbXML imported model had to be manually modified in DB to get a similar case to the BIM model.

**CLASS_A (Successfully Translated Cases):** Only two out of the twelve cases were directly and correctly interpreted in DB. The first is the unit-based model of a curved wall (test 3), meaning that medium level of complexity in geometry can be properly recognized, and the second is the room bounding elements’ thermal properties, from the cases previously tested by authors. The proper translation of thermal properties of construction materials specified in Revit is very important so that they do not have to be specified again in DB. However, in Revit the thermal properties of each material need to be specified one by one, compared to DB where each material (construction layer) carries by default its own thermal properties. In terms of time this procedure might be preferable to be done straight in DB.

**CLASS_C (Dead end cases):** Both of the cases that reached a dead end belong to the general category of Building Geometry (see Figure 7). Regarding missing topography (case previously tested by authors) it becomes apparent that gbXML schema does not support elements such as furniture, railings, light fixtures or staircases. Concerning topography, no existing relevant literature has been spotted and the findings indicate that there is no way that topography can be transferred through gbXML in DB. Depending on its geometry complexity, when the topography cannot be re-modelled in DB the case is considered a dead end. From the unit-based model tests the translation of double curved wall was not feasible, and the modelling in DB is not possible either, which implies that significant geometry simplification in DB is the only solution so far. The findings prove the considerable data interoperability limitations for complex geometries.
CLASS_B (Interoperability limitations): The rest of the tested cases are found to be partially recognized in DB. The intermediate steps of each case, as shown in Figure 7, indicate that even when an alternative way of creating the Revit model has been investigated no correct and direct translation from Revit to DB was found. Therefore, in all cases a manual modification of the ‘faulty’ gbXML model was necessary in DB. Two of the cases, ‘zone merging’ (test 1) & ‘room separation lines’ (test 2) had also been mentioned in existing relevant literature and their further research that was suggested in this study revealed some additional interoperability issues. Note that the finding in the case of ‘room separation line’ (line creates separate room) contradicts the case of existing literature. There the room separation line could not be recognized in DB due to earlier version of DB that was used. That fact denotes the importance of the version of software used in every test. Comparison of findings for same cases using different versions of the same software could be a good indicator of the development of each software (BIM or thermal analysis).

*Model geometry distortion*

The second issue that the discussion deals with, is the extent of model geometry distortion and the level of manual modification in DB needed. It concerns the cases that present interoperability limitations but their modification in DB is feasible in order to get a respective to Revit model case (Class B). Those cases are split between medium and high level of geometry distortion. Using the example of the double height space/atrium (test 6) the non-recognition of the intermediate slab in DB when one room is specified in Revit or the removal of the hole in DB when two rooms are specified in Revit is considered a limitation that requires manual modification and partial re-modeling in DB. Similarly, in test 7 although the vertical shading planes are recognized as geometry the fact that they are recognized as shading surfaces in DB (planar surfaces without thickness and thermal properties) reduces the level of geometry interpretation accuracy. The missing horizontal shading surface (test 8), the missing hole on the wall (case 2 previously tested by authors) and the curved curtain wall (test 5) allow for remodeling in DB but the level of geometry distortion (missing geometry) is too extended. For example, in test 5 the curved wall is recognized but without the openings. Although the openings can be manually added in DB the process is time wasting especially when the exact percentage of glazing / frame respective to Revit model needs to be achieved.

*Impact on thermal analysis*

The geometry interoperability limitations should also be read in conjunction with the impact that these limitations have on the thermal analysis results in DB, which is the third issue that the discussion deals with. For instance, again in test 6 if the model is left with two separate rooms as imported by gbXML and no hole in the slab is created in DB, that could lead to significant deviation of the actual solar gains in the ground floor. This result would be misleading if the geometry is not modified in DB and the difference in the results between the ‘correct’ and the faulty’ model cannot be neglected as it is more than 10%. Generally, when the percentage of difference is less than 10% like in tests 1 & 2 it might be neglected and possibly the alteration of gbXML imported model is not crucial.

**Conclusion**

In order to link BIM software and BPS, gbXML and IFC have been developed as the main data exchange schemata. Interoperability limitations between the two schemata were investigated in the first part of the study. From a general comparison between them it is indicated that the path through IFC is more complicated and the final data translation in OS
is more primitive. This finding is consistent with the conclusions of other researchers who have documented the limitations of software translators when using IFC (Chen et al 2017). However, it has not been specified in this study whether the problem lies in the IFC schema or the intermediate step of BIMserver. The second part of the testing was based only on the gbXML schema. A taxonomy of unit–based model cases was formed, and each case was tested individually, following a specific testing pattern.

A categorization of tested cases classifies them according to the extent of successful data interpretation. From the results of the tests it is concluded that the stage of interoperability between BIM (Revit model) and the simulation field (DB) is questionable, due to issues concerning distortion of model geometry, missing data or misinterpretation of spatial specifications in most of the cases. The effort and time spent to correct the gbXML models in order for them to reach a proper level of data accuracy, necessary for thermal analysis in DB, is also considerable. The investigation not only indicated cases of data misinterpretation, but also explored the impact of these limitations on the energy simulation field.

The investigated test cases act as a contribution to the scientific community, adding more cases concerning interoperability issues of gbXML for the specific path: Revit → gbXML → DB. Moreover, a generic, systematic and algorithmic-based procedure for data interoperability investigation is formed based on a specific testing pattern. Furthermore, a taxonomy of existing and suggested cases for study has been proposed. It encompasses an open-ended structure, providing a basis for other researchers to expand the existing literature and to map data interoperability issues based on the same testing methodology.

Future work

Suggestions for future work include the further investigation of the path through the IFC schema, not only through the BIMserver but also through other possible ways to reach directly from Revit to OS or other GUI that leverage EP as the simulation engine. Furthermore, the established research methodology can be applied in different import/export pathways, such as gbXML import from other BIM programs (e.g. ArchiCAD) and export to different simulation engines (e.g. IES, eQuest etc) and their respective GUI. Yet, to continue to insist on building geometry-focused BIM models first and then attempting to translate them to energy models will always be fraught with interoperability issues (Ando et al 2018). Other researchers have suggested that a lightweight conceptual model may first be needed to be constructed (Aish and Pratap 2013) that is then used as a scaffolding for a more detailed BIM model. One approach we are currently following involves a formal encoding of topological data in a building model (Jabi 2016; Jabi et al 2017). We found that a data representation called non-manifold topology (NMT) is ideal for lightweight representations of a building as an envelope with internal cellular subdivisions. The topological consistency of NMT enables topological of these cellular spaces and surfaces and thus their further analysis. This lightweight and consistent representation was found to be well-matched with the input data requirements for energy analysis simulation software.

Acknowledgement

This work was supported by a Leverhulme Trust Research Project Grant (Grant No. RPG-2016-016).
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Usability assessment of building performance simulation tools: a pilot study

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Abstract: Due to climate change, the built environment is facing increasingly strict environmental targets. Thus, architects are challenged to design evermore high-performing buildings, a task for which they can no longer depend solely on their experience and intuition. Building performance simulation (BPS) tools have become central in this context to support the design process. Yet, several studies show that such tools are still not widespread among practitioners at early design stages. Despite significant efforts made to deliver more “architect-friendly” tools, a gap remains between the expected use and the reality, highlighting the need to adapt the design approach when developing such tools. A user-centred design approach seems promising for increasing the usability and acceptance of BPS tools, and should be fine-tuned through multiple iterations between BPS developers and potential users via usability assessments. However, as usability assessment has its origins in the domain of human-machine interaction, no methodology has been proposed yet specifically for BPS tools. This paper is the result of a first interdisciplinary pilot study, describing and evaluating a usability assessment method for a new BPS tool that supports the low carbon building design process. Usability, the reliability of the tool and its usefulness are amongst the dimensions that have been assessed with a selected population of future users. Moreover, recommendations and guidelines for the reproducibility of the test are provided. The study shows that both, the quantitative and qualitative results gathered through a usability assessment are insightful to develop a BPS tool that is efficient, satisfactory, pleasant to use and widely adopted by designers.

Keywords: UX, Usability, Building Performance Simulation, User Test

Introduction

It has been estimated that, in Europe, built environment accounts for more than 40% of total CO₂ emissions and 45% of the total final energy demand (Sutherland et al., 2015). Thus, energy efficiency in buildings has become a key energy policy in order to reach the environmental targets settled for 2050 (EU Parliament, 2014). To meet these ambitious objectives, architects and engineers are increasingly challenged and can hardly depend solely on their experience and intuition. Consequently, building performance simulation (BPS) tools have a great potential in supporting the design process (Hensen, 2004; Negendahl, 2015).

The use of BPS has significantly grown in the last 10 years, mostly due to the use of environmental performance rating tools to obtain building certification. An important portion of assessments in LEED and BREEAM in Europe, or MINERGIE in Switzerland, are based on the building’s energy use, predicted by using BPS. However, these tools are supposed to assist architects during the whole design process, especially in the early design phase, in which important parameters affecting the building performance are addressed.

Despite significant efforts made to deliver more “architect-friendly” tools, several studies show that such tools are still not widespread among practitioners and most of the
time are used only to obtain a certification (Attia et al., 2012; Bleil de Souza et al., 2015; Soebarto et al., 2015). The same authors identified the poor usability of these tools as the main reason of the gap between their expected use and the reality. Most architects who use BPS tools in design practice are very concerned with the usability of interfaces, generally criticizing the ease of use of graphical user interfaces (GUI) deployed in this domain (Hensen, 2004; Reinhart et al., 2006; Shi et al., 2013).

Assessment of usability is an important exercise in the domain of human-machine interaction. Usability assessment, generally conducted throughout the whole development process, requires experts, developers and real user test (UT) to assess usability of a prototype (Lewis, 2006). While the method is well established and widely used in systems design, no methodology has been proposed and evaluated so far addressing particular requirements of BPS tools. This paper proposes a complete usability assessment method for BPS tools, and the results of its first application on a small sample of users.

State of the Art

Several authors have hence criticized poor usability as a common and constant negative feature of existing tools. Six BPS tools were compared in Weytjens et al., (2011) showing that no single tool is entirely satisfying architects’ needs, mainly due to poor communication and visualization of the results. Farzaneh et al., (2015) examined three different tools, and found that most often preference was given to the one with the best graphical representation of outputs and inputs. Both the above results are confirmed in an extensive comparison of the ten major BPS tools on the market conducted by Attia et al., (2009). Findings show that architects need a tool that provides a comprehensible graphical representation and a simple navigation.

Comparable conclusions have been drawn in various studies based on interviews and web-based surveys aiming at the assessment of problems in the daily use of BPS by architects (Hopfe et al., 2006; Reinhart et al., 2006; Soebarto et al., 2015). Results indicate that users look for better tools with more user-friendly interfaces and with a shorter learning curve (Mahdavi et al., 2003).

Despite the obvious importance of usability in the process of designing software and interfaces, findings of such studies indicate that developers of BPS tools have not entirely addressed this issue so far. Usability design signifies a constant improvement of the interaction of users with a system, by obtaining information about performance (e.g. efficiency and effectiveness of use), the likes, dislikes, needs, emotions and understandings of real users interacting with a system in a real operational environment (ISO 9241-210:2010).

Efforts have been conducted in different fields, but only a few publications relate usability engineering to BPS software (Holzinger, 2005; Hopfe et al., 2009). Previous work has focused on assessing the usability of a BPS tool through a heuristic evaluation demonstrating the feasibility of this expert-based evaluation method (Struck et al., 2010). However, Folmer et al., (2002) conclude their comprehensive review that none of the various usability engineering methods alone (i.e. testing, inspection or inquiry) have the capacity to support BPS software architecture.

Although the results of this literature review clearly highlight the importance of usability engineering for the development of BPS tools, the review showed also that usability seems to remain a problem with existing tools used in practice. One reason for this could be that in the development of such tools, aspects of human-centred usability design are not applied thoroughly. While only few studies have described a complete usability methodology to
assess usability of BPS tools, there is a great potential for further research to improve these tools in terms of usability.

**Usability and human-centred systems design**

To ensure the development of tools that are easy, satisfying and fun to use, it is important to guarantee that the needs and limitations of the user are taken into account throughout the whole development process (Rubin et al., 2008). This “user-centred” approach embodies three main principles of design: a) early focus on users and tasks, b) empirical measurement, and c) iterative design (Gould et al., 1985).

This implies that designers should bear the end user in mind throughout the whole design process. For that purpose, the authors propose to include the user very early into the design process. To do so, users should use prototypes of the product to carry out real tasks while their performance and reactions to the product are observed, recorded, and analysed.

With regard to the scope of the usability evaluation, two different approaches can be distinguished: formative and summative usability testing. Formative testing is conducted throughout the whole development phase in an iterative design process with the goal to gather qualitative information about weaknesses and operation problems of a product. Summative testing on the other hand aims to collect quantitative data about the accomplishment of task goals. It is often conducted at the end of specific phases in the product development process or at the end of the development process (Lewis, 2006; Rubin et al., 2008).

However, usability testing is not the only technique applied in product development practice that allows evaluating the usability of a product. Other popular methods are, for example, cognitive walkthroughs, heuristic evaluations, checklists or interviews, and focus groups (Jordan, 1998; Kuniavsky, 2003; Nielsen, 2003). Each of those methods feature some advantages and disadvantages. Nevertheless, usability tests and focus groups are the only methods that consider representative end users and provide empirical data as requested in the user-centred design principles (Gould et al., 1985). Therefore, usability testing and focus groups are among the most important and widely applied methods in usability practice.

**The case study, ELSA**

In order to realize efficient buildings with a low environmental impact, the analysis of the energy performance must be integrated since the early design stage. Designers are then facing the problem of quantifying and foreseeing the CO₂ emissions of a building when a lot of major architectural and technical solutions (under the environmental point of view) are still undefined. This leads to a time mismatch between the moment a building is designed and major decisions are taken, and the moment when a complete knowledge of the consequences of a design choice is gained.

We proposed in a previous study a methodology to address this different detail resolutions in energy simulation (Jusselme et al., 2016). This method has then been put into practice in the research framework of the smart living lab (Jusselme et al., 2017), developing a first functional prototype called ELSA, which stands for Exploration tool for Sustainable Architecture (elsa.epfl.ch). This tool couples parametric energy simulation with sensitivity analysis (SA), in order to provide useful information about the connections between different design parameters and their influence on the performance of the building. In order to perform a SA, it was necessary to assess a large number of design alternatives. This led to the creation of a large database, with thousands of alternatives. To explore the database, several
innovative data visualization techniques have been tested in order to find the most suitable one to stimulate the user to investigate the design space (Jusselme et al., 2017).

It was indeed crucial to evaluate the usability of the different GUI, unveiling strengths and weaknesses of each. Accordingly, we performed a UT in order to receive constructive feedback for further development of the tool. Two different GUI were compared. The first one, in Figure 1, uses the Parallel Coordinates (PC) visualization technique, which allows to interact with a large number of parameters and to explore relationships among these.

This visualization method is expected to empower the designer with data analysis capabilities that are important in the early stages of building design. Each vertical graduated axis represents one parameter, with each value being displayed as one tick. A design alternative is represented by a polyline crossing all axes at the corresponding parameter values. With the use of brushing methods, the user can specify a range of values on each dimension. This reduces the number of design alternatives displayed and unclutters the overview. More details on the use of Parallel Coordinates to display building energy performance data can be found in Jusselme et al., (2017). The second GUI, depicted in Figure 2, is called Stacked Coordinates (SC). The same has been specifically designed for this case study by the EPFL+ECAL-Lab Design research Center (Koller and Florentine, 2016).
Using SC, users can take one design parameter after another and assess the impact of each of them. Not only how they affect building performance, but also how they reduce the number of solutions for all the next choices still to come. The interface suggests the most influential design parameters, guiding the users through the desiderata options.

User test objectives

The study was intended as a first and unique pilot work to unveil the complexity of running a usability study for BPS. Moreover, the UT was meant to improve the usability of the ELSA tool under development with the results of our summative and formative tests. We defined the key dimensions to assess through the UT:

- User satisfaction and perceived usability.
- User learning.
- Affect and emotions.

Along these dimensions, we wanted to compare the usability and usefulness of two BPS tools in the early design phase. We wanted to verify the three following hypotheses:

1. Whether the use of SC or PC increases the feeling of control of the architect towards design-oriented tasks.
2. Whether using SC or PC increases (and to what extent) the knowledge of the user regarding environmental performance.
3. Whether the SC receives higher usability ratings than PC in the user evaluation thanks to its decision-tool oriented features including suggestions of the most impactful parameters and the constructivist approach, which help to reduce cognitive load and hence increase user performance and satisfaction.

Study design and procedure

We designed our study as a "within-group" experiment with Master-students in Architecture. The independent variable was the type of visualization tool used: SC or PC, meaning that each participant used both visualization tools to complete the same set of tasks. Participants who used SC in the first session had to use PC in the second session, and conversely. We conducted the study over two different sessions, three weeks apart. Each session was divided into 10 steps. We chose to use both summative and formative approaches already mentioned in the previous section. The 10 steps were as follows:

1. Assessment of affective state – baseline measure

   Emotions are an important component of the user experience. They can strongly affect how a user perceives and appreciates an interface (Agarwal et al., 2009). Thus, affective state was measured based on the Self-Assessment Manikin model (SAM; Bradley et al., 1994) twice during each testing session, before (baseline measure) and after interaction with the system (step 6). On three single items, SAM assesses pleasure (positive – negative), arousal (excited – calm) and dominance (high – low) on a nine-point scale. This instrument provides a quick, reliable and non-linguistic way to assess the emotions of the participant related to their response to the tool.

2. Introduction class

   The performance of the user in building design tasks using BPS software is influenced by his knowledge regarding the design of energy-efficient buildings. Since one of the goals of this study was to assess the gain in knowledge thanks to the two tools proposed, this part consisted in giving some information to the user about the context of use of the tool, while
giving minimal information about BPS. We explained the goal of the user test and what was expected of the participants. We gave background information about the ELSA project, followed by an explanation of how an energy assessment tool can be used in order to design energy-efficient buildings. We were careful not to go into details on environmental concepts, to avoid bias of knowledge tests’ results (steps 3 and 8). For the sake of reducing effects linked to social comparison, we informed participants that we would evaluate the performance of the two groups rather than their individual performance (Buunk et al., 1990).

3 - Knowledge test

In order to assess the usability of BPS, a summative approach seems essential. This test allows to determine whether the user gains knowledge by using any BPS tool. Learning was measured via a knowledge test. This test consisted in 10 multiple-choice questions (e.g. “Which window type is best regarding CO₂ emissions?”) assessing participants’ knowledge regarding environmental awareness and the design of energy-efficient buildings before an interaction with the tool took place. A similar test was conducted a second time after using the tool in order to assess the learning outcome of tool usage. The second time we randomized the order of questions to avoid any bias related to the order, and to minimize priming effects (Tourangeau et al., 2000) (step 8).

4 - Tutorial

At this step we divided the class into two groups. The group was determined by the ID randomly assigned to each participant at the beginning of the session. Each group was assigned to one of the two visualization tools, and we explained its functioning. Participants used the tool on their own computer (Mac and PC laptops) in order to reduce the extraneous cognitive load as much as possible (Chandler et al., 1991). Their working environment was thus as familiar as possible: they used their own computer, devices and operating system. We set up a video-capture tool on the computer screen of each participant. Screen recordings allowed to measure the time needed to accomplish each task.

5 - Tasks

Again, the summative approach was used in this step. This step allows measuring the performance of the user in a set of tasks that are inherent to the design of energy efficient buildings. It consisted of six specific tasks. Participants were asked to perform different practical activities using only the tool. The tasks were classified into four types:

- Exploration: to find out the relations between different design parameters and the environmental performance of the buildings. Discover and understand how different design choices affect the energy consumption.
- Configuration: to introduce and evaluate their own project. Participants were asked to input the project they had in mind to realize their building and estimate its environmental performance.
- Improvement: to reduce the total environmental impact of their project. Once that a first assessment of the project was done, users were requested to change some design choices to improve the overall performance.
- Frequency: to create a project following some specific constrains. In this case the freedom of the users was limited to few parameters to quickly reach the desired result.

6 - Emotional Test II

After all tasks were completed, we asked participants to rate their affective state using the SAM a second time, to measure the emotional response after the use of the tool.
7 - UX Questionnaire

For this step, we chose to use another summative approach and we asked the participants to rate the perceived usability of the tool using the widely accepted System Usability Scale (SUS; Brooke, 1996). This instrument can be considered an industry standard and offers several advantages: it can be used on small sample sizes, it is reliable and it can effectively differentiate between usable and unusable systems (Bangor et al., 2008). Questions in this test include: “How much did you trust in the information?”, “How much did you like the tool?”, “Would you use it on a regular basis?”.

8 - Knowledge test II
9 - Break
10 - Focus Group Discussion

The end of the session seems to be the ideal time to run a formative test: users have been using the tool for an extended period of time, and they identified weaknesses and strengths of the BPS tool. In our experiment, we gathered each group in a separate room and asked for their feedback regarding the tool and its usefulness in the early design stages. More specifically, with the scope of a formative usability evaluation (Lewis, 2006), this discussion was intended to help understanding which features were considered useful and which not, and how the interface could be improved in order to suit the needs of architects. The questions we asked were all the following:

- How would you use this tool in your future practical work?
- What was useful, what was not?
- What do you think about the design of the interface? What could be improved?
- Do you think that this tool might improve the communication with stakeholders in future project?
- What makes you trust the tool and the information it provides?

Results

In this section, we present the results of the pilot study, conducted over the two sessions (I and II). Ten subjects took part in Session I, and eight took part in Session II. The whole study was designed as a within-group experiment, therefore we removed the answers of two subjects in the first session since they did not attend the second session, for a total of eight participants. Due to the small sample size typical in usability tests, most statistical comparisons did not show significant differences. Therefore, effect sizes and confidence intervals are reported in addition.

System Usability Scale (SUS) Questionnaire

Analysis of the data on perceived usability (c.f. Figure 3) indicated that both systems do not differ with regard to their obtained ratings on the SUS scale ($t(7) = 0.08, p > 0.05$) with a Cohen’s $d$ (using pooled variance) of 0.04, representing a very small effect. Although no difference in the usability-evaluation was observed, confidence interval for the usability-ratings of the PC tool was considerably larger than for SC.
The total usability score for the two visualizations was very similar as the Stacked Coordinates earned 72.2 (SD = 10.0) while the Parallel Coordinates earned 71.6 (SD = 21.3). According to established norms (Bangor et al., 2008), both scores can be considered "excellent".

**Emotional reaction**

Participants had to report their experienced emotions before and after using the tool. Figure 4 displays the change scores (score after interaction – baseline measure) for each of the three SAM measures. Results indicate that measures of pleasure were very similar for both tools. A paired t-test indicates no significant differences ($t(7) = 0.48$, $p > 0.05$, $d_{pooled} = 0.25$, small effect). Similar results were obtained for the measure of arousal ($t(7) = 0.67$, $p > 0.05$, $d_{pooled} = 0.31$, small effect), and dominance ($t(7) = 1.13$, $p > 0.05$, $d_{pooled} = 0.50$, medium sized effect). Interestingly, the slightly higher dominance ratings for the PC tool show a smaller confidence interval than the dominance-ratings for the SC tool.

**Performance indicators**

The main function of the tools is to support architects to improve environmental performance of their designs. One task required participants to input their own project and then improve it by using the BPS tool. A comparison of the change in energy consumption after use of the tools indicates that improvements in energy consumption were higher when participants used PC compared to SC (Figure 5). This effect was significant ($t(7) = 2.36$, $p < 0.05$) with a Cohen's $d$ (using pooled variance) of 0.945, representing a large effect.
Additionally, in a configuration task, participants were asked to filter out different design parameters and find one design alternative complying with the given environmental indicator threshold. With SC, participants needed lesser parameters compared to PC (see Figure 5), indicating that SC requires significantly less steps to reach a given target \((t(7) = 2.87, p < 0.05)\) with a Cohen’s \(d\) (using pooled variance) of 0.961, representing a large effect.

In the frequency task, participants had to input a set of parameter values, and then answer with the exact amount of alternatives left. SC users gave 50% of correct answers, and PC users gave 12.5% of correct answers, non-parametric analysis (Wilcoxon signed-rank test due to violation of normality-assumption) however indicates that this difference is not significant \((T_+ = 12.0, T_- = 3, z = 1.342, p > 0.05, r = 0.335, \text{representing a medium effect})\).

**Knowledge test**

We computed the total score for all the questions of the knowledge test. The mean values and 95% CIs are shown in Figure 6. Overall, the scores increased for both tools, meaning that participants gained knowledge while using them. A repeated ANOVA measure indicated that this effect was statistically significant \((F(1,7) = 7.0, p > 0.05, \eta^2_p = 0.5)\). The comparison between the two tools did not reach significance level \((F(1,7) = 2.3, p > 0.05)\), neither did the interaction of tool x time \((F(1,7) < 1, \eta^2_p = 0.045)\). Interestingly, CI for PC increases after interaction with the tool compared to SC which decreased.
**Focus Group**

The group discussion was very useful to gather some qualitative results about the whole experience and the two GUI. In this moment the users felt free to share their impressions and we could really understand the strengths of both visualization methods.

The main strengths of the Parallel Coordinates can be summarized through the following statements: “it is easy to track a single project from the left to the right across each polyline”, “it is useful to see how, at the beginning of the design process, just changing a parameter the building performance can vary a lot”, and “it seems very professional because it uses a scientific way to represent the data”. On the other side the principal weak point of this visualization is that “at first sight it is overwhelming, looks too complicated”.

Instead, in the Stacked Coordinates, proposing parameters through a sensitivity analysis was really appreciated: “It is nice to have the two ways of describing the project (as you want and per sensitivity), because it shows us that we should think differently regarding the parameter definition into the design process”. In the case of the SC the novelty in the design has been turned into a down factor, as “if you go to a client with it they will think it is more commercial and they will not trust the results so much”.

**Discussion**

The results of this pilot study have enhanced our understanding of usability in building performance simulation tools. Moreover, the work showed the great potential of a usability assessment for increasing the acceptance of BPS tools. The combination of the quantitative results gathered through a summative approach, and the qualitative ones obtained through a formative approach, have brought benefits in the development of ELSA.

The summative approach was positively used to assess the user learning, user satisfaction, and perceived usability of the tools. The quantitative results to evaluate these dimensions were obtained through the knowledge test, the performance indicators, the SAM, and the SUS. These methods represent an innovative application of the human-centred systems design approach applied to BPS tools and offer considerable insights regarding the two GUI. The Stacked Coordinates provided a better understanding of all the features of the parameters and the process, as showed by the results of the configuration tasks. Moreover, SC implied a lower cognitive load, providing more guidance to reach the objectives, as confirmed by the frequency tasks. Parallel Coordinates instead gave more interactivity and flexibility, as the whole set of alternatives is visible from the beginning. The result of the improvement task showed a higher improvement of the environmental performance of the project using PC.

Alternatively, the formative approach was used to better understand the wishes and the requirements of the users, based on which it has been possible to continue the development of ELSA. The group discussion, combined with the summative results, lead us to think that coupling both SC and PC strengths into a single tool could empower the user. Indeed, PC helps to give an overview on the dataset and the correlations between dimensions, while SC helps the user to choose the best parameters and reduces cognitive load with its constructivist "building blocks" approach. Once the prototype of the new tool is available, it will have to be tested again with this UT, in order to compare the results with the previous versions and observe the improvements achieved through this usability assessment.
Conclusion

The literature review revealed that despite usability being a crucial aspect in the process of designing software and GUI, so far no usability assessment method has been proposed specifically for BPS tools. This paper aimed to fill this gap, proposing a complete User Test to assess the usability of the new developed energy tool, ELSA. According to the user-centred design approach the usability of a product should be tested very early in the development process. Therefore, two functional prototypes were provided to the users, based on two visualizations methods: Stacked and Parallel Coordinates.

The objective of the UT was to verify three hypotheses regarding the usability and usefulness of two BPS tools in the early design phase. The first one, stating that the use of SC and PC increases the feeling of control of the architect towards design-oriented tasks, was partially confirmed by the results of the SAM test. Both visualizations indeed increase the dominance of the user after a period of use. The second hypothesis was instead fully validated by the knowledge test. The user gains expertise on the design of energy-efficient buildings by using both PC and SC, as the results of the knowledge test increased for both visualizations. Finally, the third hypothesis was verified using the SUS test. A higher usability rating was found for the SC, due to its decision-tool oriented features. However both SC and PC achieved high scores in the System Usability Scale.

Based on those findings, ELSA will be developed further combining the key features of the two proposed GUI, with the aim to create a new prototype which can be tested with users again. This iterative process of user testing and further development is crucial in the user-centred approach and should lead finally to a functional product that corresponds with the requirements of the user. The essential role of usability tests in such a user-centred design approach found in the literature is as well confirmed for the case of BPS and indicates the importance of this evaluation method for the development of usable tools.

Acknowledgment

The work presented in this paper has been funded by the State of Fribourg (message du Conseil d’Etat au Grand Conseil 2014-DEE-22). We thank Andreas Koller for his valuable contribution to this work.

References

Towards generation of holistic renovation scenarios using Multiple Criteria Decision Making – Case of Energy Consumption, Investment Cost, and Indoor Comfort

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Abstract: Recent research in building renovation field seeks methods for development of more holistic renovation scenarios that lives up to a broader set of sustainability objectives/criteria. The aim in this paper is to apply one of these methods – a Multiple Criteria Decision Making (MCDM) method – for evaluation of holistic renovation scenarios for an apartment block. It aims at addressing the interactions or trade-offs of the considering objectives and criteria with each other when the renovation scenarios are being developed, which is one of the major issues in this field. The intention is to demonstrate the principles and capabilities of the method, and for the sake of simplicity, the demonstration is limited to involve renovation of a few significant building components, sustainability criteria, and a limited amount of renovation measures. As such, it firstly indicates details about the key components of a sustainable renovation related to sustainability criteria and renovation approaches. The performance of a total of 55 renovation scenarios are simulated and evaluated in terms criteria for Energy Consumption, Investment Cost, and Thermal Indoor Comfort. The trade-off between the criteria is addressed using Pareto-front approach, and the optimal solution is determined using MCDM-based rating method (application of Multiple Attribute Decision Making (MADM) methods). Therefore, the paper demonstrates how application of simulation and MCDM methods in the early design stages of holistic renovation projects may improve a decision-making process, which has focus on obtaining sustainable building renovations.

Keywords: Renovation, Sustainability, Holistic renovation, Multiple Criteria Decision Making (MCDM).

Introduction

Recent investigations into the field of building renovation for energy improvements of existing buildings has got an increasing attention in many European countries (Jensen et al, 2015). Energy renovation of the existing building stock is crucial to reach EU energy and emission reduction goals without sacrificing indoor climate, building functionality, spatial quality etc. (BPIE, 2011).

The improvement of existing buildings can be divided into two major tasks: current condition assessment and formulation of upgrade strategies (Juan et al, 2011). There are various types of methods and Decision Supports Systems - DSS (Nielsen et al., 2016; Ferreira et al., 2013) that are used to cope with the key factors and challenges about these two major tasks. The present paper is particularly about the latter, i.e. how to propose renovation solutions via development of efficient renovation scenarios\. In development of more holistic renovation scenarios, it is important to include and evaluate wider objectives/criteria attached to the sustainability. The major issue here can be addressed through consideration of the interactions or trade-offs of these criteria with each other. The paper addresses the fact that the development of renovation scenarios rarely takes into consideration interactions between the various objectives of a renovation project (Kamari et al, 2017b). The results are,

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1 The term “renovation scenario” used in this study means a selection and combination of some different renovation technologies/actions (i.e. insulation of the external walls) that together build alternative renovation scenarios/packages and subsequently is applied in a renovation project.
therefore, suboptimal renovation solutions, which do not reach the full scope of sustainability for refurbished building(s).

The paper takes offset in a Multiple Criteria Decision Making (MCDM) methodology previously proposed by the authors (Kamari et al, 2017a) – a methodology for addressing interactions and trade-offs between renovation objectives/criteria in a holistic manner when generating and evaluating renovation scenarios. More specifically, this paper presents and discusses the application of this MCDM method for evaluation of simulation-based performance of the holistic renovation scenarios for an apartment block. The paper in the following is organized with a section, which summarises the key objectives in development of holistic renovation scenarios, the criteria that are used for evaluation of the simulation-based performance of the solutions/scenarios, and the renovation measures and scenarios considered in this study. Next, it provides a brief description about MCDM methodologies used. Consequently, the last two sections present and discuss the results of the study, and section 6 provides a discussion and conclusion.

Holistic scenarios for sustainable renovation

The meaning of the terms ‘holistic scenario’ and ‘sustainable renovation’ used in this paper is adopted from (Kamari et al, 2018b). The authors addressed a conceptual design framework entitled “Tectonic Sustainable Building Design (TSBD)” for the development of holistic renovation scenarios. The TSBD encompass tectonics (refers to architectural articulation theory), sustainability (refers to the holistic objectives/criteria), and holistic multi-methodology (refers to an integrated design methodology for building renovation). Saying briefly, TSBD serve as a means to unify the platform for renovation strategies for refining and improving the contemporary building sector seen in the light of sustainability, and supporting the decision-making ahead of generating renovation scenarios as holistically as possible. In the TSBD framework, sustainability is the most desired value for renovation of the existing building stock.

Sustainability objectives/criteria

Some sustainability objectives/criteria may be rather quantifiable, while others are less so. These renovation goals must be identified and targeted early in the design process while renovation scenarios are developed. Regarding the full scope of this discussion, Kamari et al. (2017b) attempts to address this through a new holistic sustainability Value Map which applies Checkland’s Soft Systems Methodologies – SSM (Checkland, 2000) together with Keeney’s Value Focused Thinking – VFT (Keeney, 1992). The Value Map consists of the three overall categories Functionality, Accountability and Feasibility (a total of 18 sustainable value oriented criteria and 118 sub-criteria have been identified within these categories, see Table 1. The major part of the criteria in the Functionality category are quantifiable while criteria in Accountability are qualitative. The Feasibility category contains a mix of quantitative (i.e. cost criteria) and qualitative criteria such as advantages in using an efficient renovation process where it influence the key stakeholders. It should be noted that the entire list of the criteria and their sub-criteria could be found out in (Kamari et al, 2017b).

<table>
<thead>
<tr>
<th>FUNCTIONALITY</th>
<th>ACCOUNTABILITY</th>
<th>FEASIBILITY</th>
</tr>
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<tbody>
<tr>
<td>Indoor comfort</td>
<td>Aesthetic</td>
<td>Investment cost</td>
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Nevertheless, the list can be extended in future research; in the current paper, the focus is to deal with the three criteria Energy Consumption (sub-criteria to energy efficiency in Table 1), Investment Cost, and Thermal Indoor Comfort (sub-criteria to indoor comfort in Table 1). This is chosen based on the prior knowledge of those who performed the experiments. The following sections elaborate on these criteria and how they are evaluated in this study.

**Energy consumption**
Reduction of energy consumption is a highly motivating criteria for renovation purpose. In this study, energy consumption is referred to reduction of energy consumption for heating measured in kWh/m²/year. The hourly dynamic simulation tool ICEbear (Purup et al, 2017) was used to calculate the heating performance.

**Investment cost**
Investment cost is often prioritized as one of the most essential criteria particularly from customers or clients views. In this paper, investment cost is referred as cost of procurement in DKK/Unit of material.

**Thermal indoor comfort**
Thermal comfort is evaluated according to class I of the adaptive method in DS15251 (EN 15251, 2007) since it is assumed that people in their home adjust their amount of clothing and vent when necessary (see Figure 1). Overstepping of class I is calculated as degree hours. The hourly dynamic simulation tool ICEbear (Purup et al, 2017) is used to calculate the operative temperature.

![Graph showing thermal comfort classification](image)

*Figure 1. The indoor classification with adaptive occupants (EN 15251, 2007).*
Renovation measures

There is a broad range of measures that needs to be considered when renovating existing buildings. Kamari et al. (2018c) based on (Baker, 2009; Boeri et al., 2014; Burton, 2012; Molio, 2016) identified a total of 139 renovation measures and grouped them into 26 categories (see Table 2).

Table 2. A-Z renovation categories from (Kamari et al., 2018c).

<table>
<thead>
<tr>
<th>A. Insulation approaches</th>
<th>J. HVAC system</th>
<th>S. Increasing solar gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. Envelope (exterior finishes)</td>
<td>K. Renewable energy sources</td>
<td>T. Avoiding overheating</td>
</tr>
<tr>
<td>C. Window (replacement)</td>
<td>L. Energy storage</td>
<td>U. Re-designing of external and internal spaces</td>
</tr>
<tr>
<td>D. Doors (replacement)</td>
<td>M. Electrical system</td>
<td>V. Common areas (interior)</td>
</tr>
<tr>
<td>E. Airtightness and damp proofing approaches</td>
<td>N. Plumbing system</td>
<td>W. Individual building elements</td>
</tr>
<tr>
<td>F. Waste facilities</td>
<td>O. Controls</td>
<td>X. Sanitary appliances</td>
</tr>
<tr>
<td>G. Building security approaches</td>
<td>P. Flooring</td>
<td>Y. Fixed furniture [essential]</td>
</tr>
<tr>
<td>H. Building site</td>
<td>Q. Interior finishes – Ceiling</td>
<td>Z. Movable furniture [opt.]</td>
</tr>
<tr>
<td>I. Structural system</td>
<td>R. Interior finishes - Walls</td>
<td></td>
</tr>
</tbody>
</table>

The following list displays some of the commonly applied renovation measures within the categories in Table 2 that have been used for development of renovation scenarios in the present paper:

- External wall insulation, A.a
- External wall finish, A.b
- Internal wall insulation, B.a
- Internal wall finish, B.b
- New wall construction, C.a
- Internal roof insulation, D.a
- Internal roof finish, D.b
- New floor construction, F.a
- New windows, I.a

Figures 2 and 3 are examples from the database of alternative solutions within the above-listed renovation measures developed for this paper. The data includes detailed properties of the different alternatives such as cost, thickness, thermal conductivity, heat transfer coefficients, and resistance.
The alternatives shown in Figures 2 and 3 are used to generate a total of 55 renovation scenarios, see Figure 6, to be analysed and evaluated using MCDM.

**Application of multiple criteria decision making (MCDM) for building renovation**

MCDM is a sub-discipline of Operations Research (Triantaphyllou et al, 1998) that can be used to investigate and assess multiple criteria through complex decision analysis. MCDM methods can address both quantitative and qualitative criteria in the analysis of conflicts in criteria presented by different decision makers (Pohekar et al, 2004). Parnell et al. (Parnell et al, 2013) discuss it as a philosophy and a social-technical process to create value for decision makers and stakeholders facing difficult decisions involving multiple stakeholders, multiple (possibly conflicting) objectives, complex alternatives, important uncertainties, and significant consequences. MCDM can provide a technical-scientific decision-making support approach to justify its choices clearly and consistently, especially for addressing issues in connection with the sustainability area (Cavallaro, 2009). MCDM can be categorized into different groups and methods (Wang et al, 2009). Popular MCDM categories are Multiple Objective Decision Making - MODM and Multiple Attribute Decision Making - MADM (Climaco, 1997). MODM can be used for decision problems in which the decision space is continuous while MADM can be used for problems with discrete decision spaces (Triantaphyllou et al, 1998). Taha et al.
(2013) discuss that the decision problem in MADM is characterized by the evaluation of a set of alternatives against a set of criteria rather than, as in MODM, where the existence of multiple and competitive objectives should be optimized against a set of feasible and available constraints.

Regarding to the full scope of MCDM application for building renovation, Kamari et al. (2017a) introduced two Sustainable Retrofitting Framework and each one including three levels of decision-making. The main reason for development of such a framework was to facilitate understanding of the design process implementation through identification of the different activities which need to be carried out. The frameworks were developed based on application of either MADM methods (option “A”) or MODM methods (option “B”) for building renovation. It was concluded that the decision-making at the third level of option “B” (based on application of MODM) can be considered as a scientific design approach and it was therefore proposed as an appropriate way for evaluation of both quantitative and qualitative objectives/criteria in an integrated design process. Using option “B”, it is able to rank renovation scenarios while addressing the trade-offs between criteria at the decision-making level 2 (see Figure 4). In this paper, we use option “B” for holistic evaluation of the renovation scenarios.

**Figure 4. Three levels of decision-making for building renovation (adapted from Kamari et al., 2017a)**

<table>
<thead>
<tr>
<th>Decision making at level 1</th>
<th>It has been designed to respond to variety of stakeholders who are involved in the renovation process as well as problem structuring of the renovation case regarding to the building conditions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision making at level 2</td>
<td>It has been formulated to address the trade-offs or correlations between the sustainability criteria and related renovation strategies.</td>
</tr>
<tr>
<td>Decision making at level 3</td>
<td>It has been addressed to make the decision on selection of the most efficient renovation scenarios, and entitled <em>Scientific Decision-making</em>.</td>
</tr>
</tbody>
</table>

Providing detailed information and comparison about various types of MCDM methods is beyond the scope of this study. However, a brief description about the method used in this paper for addressing the trade-off between the described objectives/criteria in previous section as well as the rating methods that are applied for development of the ranking of optimal solutions, is provided in the following.

Trade-offs are handled using a *Pareto-front* approach (Pareto, 1896) (also known as multi-objective programming, or Pareto optimization). This is a kind of multiple criteria decision making that solves optimization problems involving more than one objective function to be optimized simultaneously.

It is difficult to judge which of the many available rating methods that would be ‘the best’ method (Wang et al, 2009). To overcome this, one can use different MADM methods and compare their outcome (a kind of cross validation). In this paper, AHP, TOPSIS, WSM and
ELECTRE are applied. These methods are quite popular due to their mechanism, understand-
ability in theory, and the simplicity in application in multi-criteria decision-making problems
(Kamari et al, 2018a). Their general principle is summarized in the following.

**AHP** (Parnell et al, 2013; Saaty, 1980; Wang et al, 2009) uses a pairwise comparison
approach to deciding between solutions. The decision maker is then asked to state how much
more important a criterion is, compared to the other criterion in the pairwise comparison.
This is done for all possible comparisons.

**TOPSIS** (Roy, 1968; Parnell et al, 2013; Wang et al, 2009) is based on the concept that
the ideal alternative has the best level for all criteria, whereas the negative ideal is the one
with all the worst criteria values.

**WSM** (Wang et al, 2009) is based on an additive utility assumption which is shown in
the sum of products calculation for each alternative.

**ELECTRE** (Benayoun et al, 1966; Roy, 1968; Wang et al, 2009) constructs the outranking
relations and the exploitation of these relations to get the final ranking of the alternative.

**Performance evaluation of holistic renovation scenarios using multiple criteria decision-
making methods**

As described in earlier sections, a list of 55 different renovation scenarios using certain
renovation using alternative solutions for various measures were generated. The scenarios
were applied for a renovation case of an apartment block located in Aarhus, Denmark. The
apartment block is a part of a dwelling area (see Figure 5) consisting of 27 identical apartment

![Figure 5. The dwelling area located in Aarhus, Denmark](image)

The apartment block consists of 32 units with similar layout. Prior to performance
simulations of renovation scenarios, the apartment block is separated into six different types
of units, as some units are placed at the gables of the block and thereby have a larger exterior
wall area. Table 3 provides the surface area and U-values for walls, floors, and roofs of the
existing apartments.

<table>
<thead>
<tr>
<th></th>
<th>Ground</th>
<th>Roof</th>
<th>Windows</th>
<th>Walls</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apt.1</strong></td>
<td>Area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>85.64</td>
<td>21.95</td>
<td>27.54</td>
</tr>
<tr>
<td></td>
<td>U value (W/m2)</td>
<td>0.66</td>
<td>0.41</td>
<td>2.97</td>
</tr>
<tr>
<td><strong>Apt.2</strong></td>
<td>Area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>21.95</td>
<td>23.20</td>
</tr>
<tr>
<td></td>
<td>U value (W/m2)</td>
<td>0.66</td>
<td>0.41</td>
<td>2.97</td>
</tr>
<tr>
<td><strong>Apt.3</strong></td>
<td>Area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>21.95</td>
<td>23.20</td>
</tr>
</tbody>
</table>
The thermal performance of each renovation scenario was then simulated. Figure 6 illustrates energy consumption (kWh/m²/year) and Percent of Degree Hours Outside Indoor Thermal Comfort Category I (% DHOCI).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Area</th>
<th>U value (W/m²)</th>
<th>(0.66)</th>
<th>(0.41)</th>
<th>(2.97)</th>
<th>(0.60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apt.4</td>
<td>91.72</td>
<td>0.66</td>
<td>0.41</td>
<td>2.97</td>
<td>0.60</td>
<td></td>
</tr>
</tbody>
</table>

With application of Pareto-front approach, a landscape of scenarios within the three evaluating criteria is created, see Figure 7. A Pareto-front is clearly visible between the cost and the energy consumption in Figure 7a. The cost vary between less than 1 Mio. DKK to
above 5 Mio. DKK. The energy consumption vary between 20-30 kWh/m²/year and above 120 kWh/m²/year.

The energy consumption seems to decrease due to the increased investment, which indicates that an investment in renovation with the selected renovation alternatives leads a lowering of the energy consumption.

A less obvious Pareto front is visible between the cost and the % DHOCI, Figure 7b, as an increased investment improves the % DHOCI from around 2.2% to around 1.8% with an investment of approximately 2.5 Mio. DKK. A further investment appears to worsen the % DHOCI. The same is visible between the energy consumption and the % DHOCI in Figure 7c,
where decreasing in energy consumption appears to have a direct improvement of the thermal comfort level up to about approximately 40 kWh/m²/year. After this point, a decrease in the energy consumption appears to worsen the % DHOCI. In Figure 7c the improvement in energy consumption may cause fewer hours to be below the temperature limits in category I. However, the lowering energy consumption may cause overheating, which is reflected in the increase of % DHOCI when the energy consumption decreases below approximately 40 kWh/m²/year.

### Ranking of the renovation scenarios

In order to make the final decision upon the performance of the 55 scenarios, the previously described MADM methods AHP, TOPSIS, WSM and ELECTRE are applied for ranking. The rankings are based on an equal weighting of all criteria, which may not be the case for an actual renovation as stakeholders may have different opinion about the importance of the different evaluation criteria. The results represented in Figure 8. The ranks differ depending on the MADM method but their trends are following each other. Note that TOPSIS and AHP methods present exact similar rankings.

![Figure 8. Ranking of the results using four different MADM methods: AHP, ELECTRE, WSM, and TOPSIS](image)
The scenarios on the lowest part of the graph in Figure 8 include renovation solutions for all components except the floor. These scenarios are generally preferable according to the MADM methods. Two scenarios marked with a blue dot ["Insulation (Class 37) - 150 mm", "Plaster", "Insulation (Class 37) - 125 mm", "Plasterboard", "RefFloor", "New windows - Hvidbjerg Everluxx Classic"] and ["Insulation (Class 37) - 150 mm", "Plaster", "Insulation (Class 37) - 200 mm", "Plasterboard", "RefFloor", "New windows - Hvidbjerg Everluxx Classic"] have a particular low rank by all methods. The only alternative separating these two scenarios is the amount of added internal insulation on the roof.

Discussion and Conclusion

One of the major issues in holistic evaluation of renovation scenarios is how to take into account the interactions and trade-offs between different performance criteria. The paper included evaluation of a list of 55 different renovation scenarios for a renovation case of an apartment block, upon three sub-criteria, Energy Consumption, Investment Cost, and Thermal Indoor Comfort. The use of the Pareto-front approach as demonstrated in this paper seems like a useful approach. The energy consumption was observed to decrease due to the increased investment, which indicates that an investment in renovation with the selected renovation alternatives leads a lowering of the energy consumption. The same was visible between the energy consumption and the % DHOCI, decreasing in energy consumption appears to have a direct improvement of the thermal comfort. However, less Pareto front was visible between the cost and the % DHOCI. Furthermore, it seems like MCDM methods are a valuable method to rank and address conflicting criteria but this study indicates that several MADM methods should be used for cross validating the ranking – which similar studies also have concluded (Wang et al, 2009).

The major limitation of the research was about combination and development of the scenarios to include various types within wider range of available renovation measures. Additional work is needed to extend the analysis of renovation scenarios to encompass all 18 criteria and 118 sub-criteria of the Value Map in (Kamari et al, 2017b) to obtain a true holistic multi-methodology for sustainable retrofitting (following a Holistic Multi-methodology for Sustainable Renovation as discussed in Kamari et al, 2018a). Furthermore, research on how to evaluate soft criteria, e.g. various aesthetic considerations, alongside the more hard criteria evaluated in this paper is also needed.

Acknowledgement

The authors of the paper would like to show their gratitude to the Danish Innovation Foundation for financial support through the RE-VALUE research project.

References


Sensitivity Analysis for Energy Modelling based on Daylight Simulations

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Abstract: Simulation techniques for modelling the lighting and energy performance of buildings are becoming widely available. Previous research by the authors found the outcomes of lighting simulation to be substantively influenced by individual settings of various model parameters (e.g., ambient reflections and grid size), particularly for complex façades. This study postulates that this influence is also reflected on predicted energy consumptions since daylight availability affects the artificial lighting needed to meet illuminance targets and the heat transferred from the façade. To test this hypothesis, a sensitivity analysis was performed investigating the influence of various daylight simulation settings on predicted energy loads. The sensitivity analysis was based on annual simulations using a shoebox model with simple and complex façade configurations under Cairo and Nottingham climates. Daylight simulations were conducted using RADIANCE while energy analysis was run through EnergyPlus. The results were statistically analysed for annual cooling, heating, lighting and total energy loads. The analysis showed that fast-low precision daylight simulation settings of ambient reflections overestimated lighting and cooling energy loads, and underestimated heating requirements. The differences were statistically and practically significant particularly in terms of lighting loads. The results were largely dependent on climatic conditions, and the differences consistently increased in case of complex façade systems. The findings from this study are discussed in the context of the challenges that façade designers need to tackle when using simulation tools at early design stage towards obtaining plausible performance outcomes.

Keywords: Daylight, Energy, Simulation, Sensitivity, RADIANCE

Introduction

The utilization of daylight in buildings can significantly affect anticipated energy requirements in different ways. Daylight in buildings has a direct impact on reducing lighting energy demands as it replaces the artificial lighting needed to meet indoor illuminance targets (Reinhart, 2014);(Reinhart, 2004);(Wienold, 2011), particularly when using lighting control systems that constantly take into account the natural daylight coming from windows (e.g. dimming light control systems) (Reinhart, 2004);(Wienold, 2007). However, a balance must be found between maximizing daylight potential, its associated solar loads and heat transfers across the façade, and the heating and cooling demands of the building (Johnson, 1984). Furthermore, the presence of daylight has also an indirect influence on the heating and cooling energy used to offset the radiative thermal output from artificial lights.

Several simulation tools are available to support designers to dynamically model daylight availability through windows, these using a range of performance metrics (Reinhart, 2012). However, there is not yet a consistent framework that defines the input parameters, methodologies and procedures on which a simulation should be based at different design stages (Reinhart, 2011), this potentially affecting the reliability of outcomes (Jones, 2017);(Ibarra, 2009). This is particularly evident when simulating complex façade systems, whereas advanced calculations could often require significant computational time and processing power (Reinhart, 2011). In such cases, using fast, low-precision simulation settings
might still produce plausible results even if compared against high-precision settings demanding longer simulation times (Mardaljevic, 2000); (Jones, 2017). Considering the direct/indirect influences of daylight on energy demands, the uncertainty in daylight simulations expected from the settings utilised may therefore be reflected in predicted energy loads. Yet, at early design stages, the additional time and resources required by a more advanced calculation might not lead to substantial improvement in performance outcomes to drive decision making (Jones, 2017).

In response, following the presentation of some fundamental daylight simulation settings - i.e., indirect light reflection and light sensors of RADIANCE-based daylight simulation that could affect the outcomes of daylight estimates – this paper presents the findings of a sensitivity analysis investigating the influence of different simulation settings on the robustness of energy predictions, while considering issues of calculation time and power.

Daylight Simulation Settings

Ambient bounces

Among different simulation algorithms, the raytracing (Ward, 1988a); (Ward, 1988b) technique is commonly used to estimate daylighting. The calculations are heavily dependent on the number of reflections, or light bounces, onto the various model surfaces before a ray is discarded (Reinhart, 2012). Based on the raytracing method, the RADIANCE tool was developed (Ward, 1998, Ward, 1994) and validated (Ng, 2001); (Reinhart, 2001); (Ibarra, 2011); (Reinhart and Andersen, 2006). Within RADIANCE, the setting perhaps most influential to the level of detail of daylight predictions is the number of ambient bounces (ab) (Reinhart, 2012); (Mardaljevic, 2000); (Jones, 2017). This setting represents the maximum number of diffuse bounces computed by the indirect calculation (Ward, 1997). When ab value equals 0, only the direct sun/sky contribution is considered. At 1 ambient bounce, the sky and sun patch become potential sources of indirect illumination. At 2 ambient bounces, there is a potential to calculate indirect illumination for surfaces that have no direct line of sight to either the sky or the sun patch (Mardaljevic, 2000). In essence, the number of ambient bounces should be high enough so that no important ray paths terminate before reaching a source, although higher ab causes simulation running times to inflate significantly. This, however, is subject to the law of diminishing returns where, in some cases, longer-time simulations may not be worth the incremental improvement in prediction accuracy (Jones, 2017).

Recommendations for the number of ambient bounces for daylight simulation vary considerably in the literature, mostly suggesting ab values between 2 and 7 (Mardaljevic, 2000, Jones, 2017, Solemma, 2014, Tindale, 2005, Mardaljevic, 1995, Ward, 1997). However, it should be noticed that the reliability of daylight simulations may require some trial and error for ab settings, even for experienced users, since using a certain setting for a simple scene may not be adequate for complex scene calculations.

To explore this, a previous study by the authors examined the influence of individual RADIANCE ab settings on daylight estimates for simple and complex façade systems (Abdelwahab et al., 2017). The analysis showed that using low ambient bounce values (e.g. ab2) decreased simulation time but could underestimate daylight predictions, the differences detected being statistically and practically significant when compared to higher settings (e.g. ab4, ab6). Instead, using higher settings, such as ab4, produced results that had small or negligible errors compared to those obtained under higher precision setting (i.e. ab6), yet
using shorter simulation times. These results were consistent for simple and complex façade systems, although the magnitude of differences revealed some climate dependency.

**Light sensors**

Quantitative daylight evaluations are mainly based on measurements taken on the horizontal plane where paper-based visual tasks are performed (Tregenza and Mardaljevic, 2018). According to (USGBC, 2013);(IESNAI, 2012), the spacing between light sensors on the horizontal simulation grid is required to be no more than 0.6x0.6m, at a height of 0.8m from the floor (USGBC, 2013);(IESNAI, 2012);(Reinhart, 2006). According to (IESNAI, 2012), the 0.6x0.6m grid was specified as it is ‘small enough’ to adequately capture all possible work areas, whilst being comparatively quicker to calculate when compared to smaller grid sizes. Additionally, the larger the grid, the less accurate the model will be in describing sunlight penetration into the space (IESNAI, 2012).

There is, however, no evidence in the literature suggesting that a simulation based on a smaller grid might not lead to more robust results. This could be expected, for example, when simulating modern façade systems featured with solar screen and complex geometries or small perforations. In such cases, in fact, it can be postulated that a 0.6x0.6m grid might not be sufficiently spaced to capture the variations of daylight distribution on the simulation grid surface and only return the prevailing light estimates across each light sensor. This was tested by the authors in a previous study (Abdelwahab et al., 2017) that sought to explore the impact of smaller grid sizes on daylight predictions. Here, the estimated differences for illuminance were consistently negligible across all cases of simple and complex facades for point-in-time and annual basis daylight simulations. However, when using a smaller analysis grid, predictions for complex façade systems showed some differences in direct ray calculations (using the Annual Sunlight Exposure, ASE, metric as a performance indicator).

In essence, the results of previous studies show that varying simulation settings of RADIANCE parameters may lead to substantial differences in daylight estimates. On these bases, this study was design to investigate the influence of these settings on energy modelling, in terms of heat transfer from the façade, complementary artificial lighting needed to meet illuminance targets, and the radiative heat from artificial light.

**Methodology**

The sensitivity analysis was based on annual daylight and energy simulations performed using a reference office space (Reinhart, 2013);(Reinhart, 2014). The analysis was carried out under the hot climate of Cairo, Egypt, and the temperate conditions of Nottingham, UK. Daylight calculations were performed using the graphical algorithm editor Grasshopper (V.0.9.0076) linked to the daylight simulation engine RADIANCE through the DIVA V.4 tool (Solemma, 2014). The Archsim Energy Modelling plugin for Grasshopper (Dogan, 2016) took the hourly lighting schedule profiles imported from DIVA and was interfaced with EnergyPlus (V.8.2.7) (Crawley, 2004);(Crawley, 1998) where all energy simulations were run.

The following sections provide details of the optical and thermal properties of model components, the simulation engines and workflow, and the statistical analysis performed.

**Model parameters**

A model of a reference office, with size 3.6 x 8.2m and height of 2.8m, was created. The optical and thermal properties of materials were based mainly on Reinhart’s model (Reinhart, 2013), although some materials were edited in order to exclude factors that could have affected the
comparison of energy performance (Table 1). Heat flows through the internal partitions, ceiling and floor were assumed to be adiabatic. No external obstructions were considered.

<table>
<thead>
<tr>
<th>Component</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glazing</td>
<td>Glazing Double Pane Clear: T\textsubscript{visible} = 80%; SHGC = 72%; U-value = 2.71 W/m\textsuperscript{2}/K.</td>
</tr>
<tr>
<td>Interior walls</td>
<td>Lambertian diffuser with a 50% reflectance 0.15 m brick (Y = 5.38 W/m\textsuperscript{2}/K), Adiabatic surface</td>
</tr>
<tr>
<td>Exterior wall</td>
<td>35% reflectance 0.15 m brick, U-value = 2.33 W/m\textsuperscript{2}/K.</td>
</tr>
<tr>
<td>Ceiling</td>
<td>Lambertian diffuser with 80% reflectance 0.2m concrete (Y = 6.00 W/m\textsuperscript{2}/K), Adiabatic surface (office not under a roof)</td>
</tr>
<tr>
<td>Floor</td>
<td>Lambertian diffuser with 20% reflectance 0.2m concrete (Y = 6.00 W/m\textsuperscript{2}/K), Adiabatic surface</td>
</tr>
<tr>
<td>External ground</td>
<td>Lambertian diffuser with 20% reflectance</td>
</tr>
</tbody>
</table>

Figure 1 Simple (left) and complex (right) facade configurations

Since daylight simulation is heavily dependent on the interaction of light rays generated at the source with façade objects, two façade designs with varying levels of complexity were investigated for this study. The first featured a fully-glazed façade (Figure 1-left). The second, a complex façade with a ‘solar screen’ based on an egg-crate shading system (Figure 1-right), consisted of rectangular panels with dimensions of 0.45m x 0.40m with a 0.1m frame. The enclosed space featured six workstations in two rows facing the internal walls. An 8am-6pm occupancy schedule was assumed, representing a normally occupied office. Daylight saving time was considered for Nottingham but not for Cairo.

The reference office was assumed to be heated and cooled by a HVAC system during its normal hours of occupation. According to the recommended comfort criteria for general office spaces in the CIBSE Guide A (CIBSE, 2015), the set point temperatures for the Nottingham climate were 21°C for heating and 25°C for cooling. In accordance with the literature for Cairo, the set points were 22°C for heating and 26°C for cooling (Sherif et al., 2014). For both locations, the infiltration rate was assumed to be 0.5 ach\textsuperscript{-1}.

Four out of the six workstations were assumed to be constantly occupied (Reinhart, 2013), resulting in a peak occupancy of 0.13 person/m\textsuperscript{2}. The total internal appliance load was set at 8 W/m\textsuperscript{2}, this corresponding to an Energy Star rated LCD monitor and a laptop for each occupant present (Reinhart, 2013); (ENERGYSTAR, 2007). The installed peak lighting power density was set at 11.38 W/m\textsuperscript{2} assuming that four 28W TL5 recessed down lights were installed on each workstation row.

Artificial lighting was linked to a dimming unit (Bierman, 2003); (Roisin, 2008). When daylit levels fell below the target illuminance level of 300 lux, artificial lighting was switched on. This would increase the active use of daylight compared to a manual light control.
(Reinhart, 2004); (Wienold, 2007), leading therefore to maximizing daylighting from window, so the variations in energy loads following daylight estimates obtained with different settings could be tackled. For the same purpose, no internal blinds were assumed. Three light sensors were installed at each workstation row at distances of 1.2m, 3.6 and 6.0m from the window.

**Simulation settings and workflow**

The study varied the -ab calculation settings from -ab2, the minimum setting for calculating indirect light for surfaces with no direct line of sight to light sources, through -ab4 and -ab6, see Figure 2. It was assumed that the smallest pattern of light projection from complex façade systems (e.g. egg-crate, perforated shading, etc.) could be captured by a grid size of 0.2x0.2m. Hence, the size of the analysis grid varied from 0.2x0.2m (738 light sensors across floor area) to the 0.6x0.6m (84 light sensors)- the maximum size recommended by the IES for light calculations- via 0.4x0.4m (180 light sensors), see Figure 3. All variables were examined for the south and west façade orientations giving 18 cases in total for each façade type (i.e. simple and complex) under each climate (i.e. Cairo and Nottingham).

![Figure 2 RADIANCE parameters (ambient bounces) used in the sensitivity analysis.](image)

At a first stage, DIVA was used to pre-calculate daylight and hourly artificial lighting schedules. These calculations were produced for each time step in a year for each value of ambient bounces and grid size. At a second stage, Archsim integrated light schedules into the thermal zone in order to calculate energy loads. This workflow was followed for each façade type and location. The study analysed energy loads arising from artificial lighting, heating, cooling and the sum of all these, ‘total energy load’, expressed in kWh/m²/annum.

**Statistical analysis**

A multiple regression with linear fits was used to analyse the data. This allowed to examine the correlation between energy loads obtained under different simulation settings for each of the cases studied. The root-mean square error (RMSE) was calculated to rigorously examine the differences detected between comparisons. The Cohen’s d coefficient was used as an estimation of the effect size, a standardised measure of the difference between groups of data with varying simulation parameters. The interpretation of the outcomes for the linear fits ($r^2$) and for the effect size ($d$) was based on published benchmarks (Ferguson, 2009), where: $r^2<0.04$= negligible; $0.04\leq r^2<0.25$= small; $0.25\leq r^2<0.64$= moderate; $r^2\geq0.64$= large and $d<0.41$= negligible; $0.41\leq d<1.15$= small; $1.15\leq d<2.70$= moderate; $d\geq2.70$= large.
Results and Discussion

Under the Cairo climate and during occupancy hours, no heating energy loads arose for the specified set points. This generally complies with other studies in the literature conducted under hot clear sky climates with no or almost negligible heating requirements (Sherif, 2012); (Sherif et al., 2014);(Singh et al., 2016). Conversely, for the Nottingham case, no cooling loads arose from the simulations.

In general, lighting loads increased when applying the solar screen under both climates due to the complex façade reducing the illuminance levels reaching the working plane. The average of lighting loads under Cairo increased by almost 7 times when applying the solar screen, whereas the average loads increased by 3 times under Nottingham (see Figure 4 for the simple façade and Figure 5 for the complex façade). As expected, the complex façade system significantly reduced the cooling loads under the Cairo climate compared to the case with the fully glazed façade. In fact, the complex facade blocked direct sunlight, provided shading and reduced heat transfer through the facade. This caused the average cooling loads to reduce almost by half. These results agree with the findings from a previous study (Sherif et al., 2010), showing that external solar screens are effective in reducing cooling demands. Conversely, the solar screen caused an increment in the average heating loads by almost a third compared to the fully glazed façade under the Nottingham climate.

Ambient bounces (-ab)

Figure 4 and Figure 5 show the results of energy simulations based on lighting calculations using different values of ambient bounces under both climates.
The data generally show that using a higher precision setting of ambient bounces (i.e.-ab6) results in lower lighting loads predictions, for Cairo and Nottingham, in the case of both façade systems, although reductions are much less evident for the complex façade under either climate. A reduction in lighting loads could have been expected due to a higher estimation of daylight availability when more light reflections (-ab) are considered for indirect calculations. Thus, the illuminance target of 300lux could be mostly met across the floor area for a significant proportion of the day. The results also showed a slight reduction in cooling loads for both façade systems estimated under Cairo based on lighting calculations with high ambient bounces (-ab6) compared to low ambient bounces (-ab2). On the other hand, an increase in estimated heating loads could be detected for Nottingham for both the simple and complex façade. As noted before, higher precision settings lead to increased daylight in the space. By proxy, artificial lighting is switched on less often, therefore reducing potential gains from this source, as already evidenced in the literature (Bourgeois et al., 2006).

A statistical analysis of the data was performed to establish the influence on energy loads of varying the -ab settings of daylighting calculation. For each comparison under different values of -ab, the analysis considered 6 cases (2 orientations x 3 grid sizes) for both façade types (simple, complex) under Cairo and Nottingham climates. Table 2 shows the estimated $r^2$, RMSE and Cohen’s d coefficients for each comparison between energy simulation results. The highest value of -ab was taken as a benchmark for each comparison.

<table>
<thead>
<tr>
<th>Climate</th>
<th>Ambient bounces</th>
<th>Energy loads</th>
<th>Simple façade (Fully glazed)</th>
<th>Complex façade (Solar screen)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$r^2$</td>
<td>RMSE [kWh/m²/a]</td>
</tr>
<tr>
<td>Cairo</td>
<td>-ab2 vs. -ab4</td>
<td>Lighting loads</td>
<td>0.12</td>
<td>5.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.99</td>
<td>4.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>9.68</td>
</tr>
<tr>
<td></td>
<td>-ab2 vs. -ab6</td>
<td>Lighting loads</td>
<td>0.28</td>
<td>5.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.99</td>
<td>4.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>10.09</td>
</tr>
<tr>
<td></td>
<td>-ab4 vs. -ab6</td>
<td>Lighting loads</td>
<td>0.39</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.99</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>0.48</td>
</tr>
<tr>
<td>Nottingham</td>
<td>-ab2 vs. -ab4</td>
<td>Lighting loads</td>
<td>0.98</td>
<td>7.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>0.99</td>
<td>4.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>3.68</td>
</tr>
<tr>
<td></td>
<td>-ab2 vs. -ab6</td>
<td>Lighting loads</td>
<td>0.94</td>
<td>8.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>0.99</td>
<td>5.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>3.66</td>
</tr>
<tr>
<td></td>
<td>-ab4 vs. -ab6</td>
<td>Lighting loads</td>
<td>0.96</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>0.99</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>0.89</td>
</tr>
</tbody>
</table>

$r^2<0.04= $negligible; $0.04 \leq r^2<0.25=small; 0.25 \leq r^2<0.64= moderate; r^2 \geq 0.64= large$

0.41sd<1.15=small; 1.15sd<2.70= moderate; ≥2.70=large

**Lighting loads**
In the case of simple façade configuration, the inferential data from Table 2 shows that using -ab2 tends to increase the estimation of lighting loads. This is revealed by the weak correlation
against its equivalents of -ab4 and -ab6 specifically under Cairo ($r^2<0.28$), although the correlations are stronger under the Nottingham climate. The estimated errors from -ab2 were considerably high relative to the actual lighting loads obtained under both climates (RMSE values around 5 kWh/m²/annum under Cairo and 8 kWh/m²/annum under Nottingham). The differences between lighting loads corresponded to large effect sizes (Cohen’s $d≥2.70$) under both climates. Using -ab4 led to a stronger correlation with the results obtained with -ab6 in terms of estimated lighting loads. The analysis generally showed negligible errors (RMSE <1 kWh/m²/annum) under both climates. This suggests that using low -ab for lighting calculations might lead to an overestimation of lighting loads, while -ab4 can produce predictions similar to -ab6 but with shorter calculation times. However, it should be noticed that the analysis detected some differences that have moderate and small magnitude of effect under both Cairo and Nottingham, hence inferences should be treated with caution.

For complex façade systems, using low -ab settings (-ab2) generally resulted in lower errors in lighting loads compared to the fully glazed façade. When comparing -ab2 to -ab4 and -ab6, the differences detected corresponded to errors of 1.69-3.81 kWh/m²/annum for Nottingham, and 3.49-4.71 kWh/m²/annum for Cairo. The estimated effect sizes were practically relevant for most comparisons under both climates. This indicates that using low ambient bounces for complex façades can also lead to an overestimation of lighting loads, although the errors are generally lower than the simple façade. Instead, using higher value of ambient bounces (i.e. -ab4) led to strong association between lighting loads when compared to -ab6 with marginally low RMSEs under both climates (RMSE≤2.4 kWh/m²/annum). Therefore, this shows that -ab4 can result in reasonable predictions of lighting energy for complex facades compared to -ab6, although again some differences with moderate effect sizes were detected.

In general, these results show that the using low -ab settings of indirect light calculation can potentially lead to an increase in the estimation of lighting loads with practically relevant errors compared to higher precision settings.

**Heating loads**

In the case of the simple façade, comparing heating loads data obtained under -ab2 with results using -ab4 and -ab6 for Nottingham showed strong associations ($r^2=0.99$), although RMSE returned relevant errors relative to the actual heating loads (4.01-5.15 kWh/m²/annum). This leads to postulate an underestimation of heating loads with differences generally of small magnitude. Instead, using -ab4 against -ab6 resulted in a strong correlation with marginally low errors and negligible magnitude of differences. This leads to conclude that, also in this case, using -ab4 for lighting calculations can be acceptable when predicting heating requirements for simple facades at early design stage.

In the case of the complex façade, strong associations ($r^2≥0.86$) were detected when comparing heating loads obtained with both -ab2 and -ab4 to the results using -ab6, with RMSE values relatively low compared to actual heating loads (1.03 to 2.38 kWh/m²/annum). However, differences with small and moderate effect size were detected for these comparisons. These results suggest that heating energy can be underestimated based on lighting predictions obtained with low ambient bounces (i.e. -ab2) compared to higher precision settings (-ab6). It is important to note that estimating heating loads based on light calculation with -ab4 provided results similar to -ab6 in the case of simple façade. However, for complex facades, a difference of moderate effect size between -ab4 and -ab6 was detected, showing that choosing between these -ab values might affect heating predictions.
Cooling loads

For the fully glazed façade, the analysis detected a strong correlation ($r^2 \geq 0.99$) between cooling loads for all comparisons under Cairo climate. The estimated RMSEs were generally negligible relative to the actual cooling loads ($\leq 4.66 \text{kWh/m}^2/\text{annum}$), although differences associated to effects sizes of small magnitude using -ab2 were detected. Conversely, the comparisons between -ab4 and -ab6 resulted in negligible differences. Correlations were weaker in the case of the complex façade. For this façade type, the analysis detected differences with moderate or higher magnitude of effects for all comparisons.

These results show that using low settings of ambient bounces (-ab2) for light calculations can also affect cooling requirements. Instead, a choice of higher ambient bounces (-ab4 and – ab6) lead to similar results for simple facades, but it may significantly impact the estimation of cooling loads for the complex façade system.

Total energy loads

In the case of the simple facade, comparing total energy loads based on lighting calculations with low ambient bounces (-ab2) led to strong association with the results obtained under other simulation settings ($r^2 \geq 0.99$). The estimated RMSEs are relatively low (about 4 kWh/m²/annum) for Nottingham, but are higher under the Cairo climate (RMSE 10 kWh/m²/annum) leading to some differences with moderate magnitude of effect. This might suggest that-ab2 could be more suitable depending on specific climates conditions. On the other hand, using higher ambient bounces (i.e. -ab4) led to an overall strong correlation in total energy loads compared to -ab6 with a negligible magnitude of differences and low errors (RMSE<1 kWh/m²/annum) under both climates.

Results of total energy loads for the complex façade system are mostly similar to the simple façade configuration, although the estimated differences are generally higher with moderate effect sizes (1.15≤d<2.70) for most comparisons under both climates.

In summary, the results of the sensitivity analysis show that increasing the value of ambient bounces used for lighting calculations can affect differently the estimation of final lighting, heating and cooling loads. More specifically, the findings suggest that using a low value of ambient bounces, i.e. -ab2, may substantively affect the outcomes of the energy simulation especially in terms of lighting loads estimation, while -ab4 generally results in final energy loads that are similar to those obtained with higher precision settings (i.e. -ab6). However, it should be noted that using -ab4 may not always lead to predictions consistent to -ab6, since some differences of practically relevant effect size were observed for the case of the complex façade. Also, even if these outcomes should be validated under different climates and weather files, the differences detected seem to be location dependent. In fact, the estimated differences were higher for Cairo compared to the equivalents for Nottingham.

Grid size

The study compared the results of energy loads for each of the different grid sizes used in the lighting calculation, and for each façade type and location.
Table 3 Annual energy analysis: Comparisons between different grid sizes

<table>
<thead>
<tr>
<th>Climate</th>
<th>Grid Sizes</th>
<th>Energy loads</th>
<th>Fully-glazed façade</th>
<th>Solar screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cairo</td>
<td>0.6x0.6 vs.0.4x0.4 m</td>
<td>Lighting loads</td>
<td>0.99</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>0.99</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.99</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>0.6x0.6 vs.0.2x0.2 m</td>
<td>Lighting loads</td>
<td>0.97</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.98</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.98</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>0.4x0.4 vs.0.2x0.2 m</td>
<td>Lighting loads</td>
<td>0.97</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.98</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.98</td>
<td>0.33</td>
</tr>
<tr>
<td>Nottingham</td>
<td>0.6x0.6 vs.0.4x0.4 m</td>
<td>Lighting loads</td>
<td>0.99</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.99</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>0.6x0.6 vs.0.2x0.2 m</td>
<td>Lighting loads</td>
<td>0.99</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.99</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>0.4x0.4 vs.0.2x0.2 m</td>
<td>Lighting loads</td>
<td>0.99</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating loads</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling loads</td>
<td>0.99</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total loads</td>
<td>0.99</td>
<td>-</td>
</tr>
</tbody>
</table>

$r^2<0.04=\text{negligible}; 0.04\leq r^2<0.25=\text{small}; 0.25\leq r^2<0.64=\text{moderate}; r^2\geq0.64=\text{large};
0.41\leq d<1.15=\text{small}; 1.15\leq d<2.70=\text{moderate}; d\geq2.70=\text{large}$

The results presented in Table 3 show strong associations across all comparisons between different grid sizes, although the correlations detected are slightly weaker in the case of the complex façade configuration. Most of the comparisons resulted in relatively low errors (RMSEs≤1 kWh/m²/annum) for lighting, heating, cooling and total energy loads under both simple and complex façade systems. The differences detected generally have a magnitude of negligible effect size. These results show that any differences in estimation that could possibly occur using smaller grid sizes in a direct/indirect light calculation through a simple or complex façade would have no practically relevant influence on energy predictions.

**Conclusion**

This study presented and discussed the results of a sensitivity analysis comparing performance outcomes in terms of lighting, heating and cooling loads obtained under different simulation settings and for different faced types and climates. The study showed that the consistency of energy predictions can be substantively affected by the input parameters chosen. In particular, the sensitivity analysis identified that the value of the ambient bounces setting, -ab, can significantly influence the calculations, leading to practically relevant errors in total estimated energy loads, particularly for lighting demands. The differences in energy outcomes are more evident in the case of complex façade systems and are dependent on prevailing climatic conditions. In this study, the variations in lighting power and the radiative thermal output due to varying the value of ambient bounces were found to affect cooling and heating loads. The correlation between artificial lighting and heating/cooling demands is coherent with the literature (Bourgeois et al., 2006).
The findings from this study are particularly relevant at early design stage when designers have to balance the robustness of data required to inform decision making against the simulation time and computational power necessary to run the analysis. Future work should investigate the impact of other simulation settings and assumptions including user-related actions on the reliability of performance outcomes of daylight and energy.

Acknowledgements
This study was supported by a Newton-Mosharafa Fund awarded to the first author by the Egyptian Cultural Affairs and Mission Sector and by the British Council in Egypt. The funding sponsored a period of 2-years visiting PhD study at the University of Nottingham (UK) from Al Azhar University, Cairo (Egypt).

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Design of the external envelope and interior spaces of school buildings to improve environmental performance efficiency in Cairo – Egypt

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Abstract: Basic education schools are one of the most important pillars in the education system of the pre-university education stage. They play an important role in the formation of a child’s identity and culture since the young age. Despite the efforts exerted by the successive Egyptian governments to provide a number of schools to accommodate the increasing number of students, there is a lack in the efficiency of the environmental performance of the existing schools and of a fixed architectural model that is applied in most of the different climatic regions. The study examined modern design methods and standards for schools to avoid many of the existing problems faced by school buildings in Egypt. This aims to produce a new generation of highly efficient and functional school buildings capable of providing a healthy and educational environment for students and teachers, conservation of energy consumption, decrease of operating and maintenance expenses of buildings, application of sustainability principles.

Keywords: Design, Basic Schools, High-efficiency Schools, Environmental Performance, Simulation Programs

Introduction

Since 1952, the real boom in the establishment of schools in Egypt has begun and the pace of their establishment has accelerated to accommodate the increase in the number of students. This has been accompanied by the emergence of many governmental institutions that were mandated to issue the design and construction standards for schools from 1952 until 1987. The General Authority for Educational Buildings was established in 1988 to be the only body entrusted with the issuance and development of the design and construction standards for schools of various kinds, as well as the development, maintenance and restoration of schools. The school design standards were issued during the period from 1990 to 1999. Issuing or developing standards of design have stopped despite the emergence of many crises and challenges in Egypt and the emergence of many approaches to the global principles for the design of modern schools in the world.

During the current academic year, there are 45279 public education schools operating, with 419961 classrooms, and 18,608,730 male and female students, 738385 private schools operating with 62755 classrooms, 2032679 students, and 2397 experimental schools operating with 19135 classrooms and 749275 students. [Statistical Overview – Egypt, 2018].

In the last decade, Egypt has shown interest in designing school buildings according to the concepts of sustainability and high-efficiency of energy consumption, but these were individual attempts by the private sector. These concepts were not generalized to governmental schools, which represent the largest percentage of the schools in Egypt. There is a shortage, however, in applying environmental design standards for these governmental schools. Thus, such schools could not provide thermal, acoustic and visual comfort in their interior spaces. Therefore, the paper aims to develop a proposal for the principles and standards of design and evaluation of
high-efficient schools in Cairo and to raise the efficiency of environmental performance of one of the typical governmental schools as a model.

The paper aims to develop a proposal for the design criteria of high-efficiency basic education school buildings in Cairo. In addition to redesigning the external envelope of a public-school building to study the energy consumption in the current situation and after modification and comparing them to measure the amount of rationalization in consumption and to improve the efficiency of the environmental performance of the building through using simulation programs.

High-efficiency schools

Definition of High-efficiency school buildings

High-efficiency school buildings are buildings that improve the educational and health environment for students and teachers at the same time in the study spaces, while reducing the consumption of energy and resources in all their forms and reduce the expenses spent on the school building (i.e. Maintenance & operation) [Colker, R., 2001].

Design objectives for high-efficiency schools

Table (1) shows the most important design goals for high-efficiency schools. For example, constructing high-efficiency buildings, in terms of design, providing economic efficiency in aspects of operation and maintenance of the school building and applying the principles of sustainability [Council, S.B.I, 2001].

Table 1. shows the main objectives of the design of the high-efficiency school building.

| Constructing high-efficiency buildings in terms of design | • Providing high levels of acoustic, thermal and visual comfort in study spaces.  
• Maximizing the natural lighting factor in school spaces.  
• Increasing air efficiency in study spaces in the school building and saving the environment in general. |
|---|---|
| Providing economic efficiency in the aspects of operation and maintenance of the school building | • Analysis of energy consumption in order to increase the efficiency of consumption to the highest levels.  
• Analysis of the cost of the building life cycle in order to reduce the total costs paid by the owner, while maintaining the design objectives set by the decision makers. |
| Applying the principles of sustainability to the school building | • Activating policies for energy conservation and application of renewable energy policies to the school building  
• Increasing the efficiency of mechanical systems and artificial lighting systems within the school building.  
• Using environmentally friendly materials and products.  
• Managing and reducing the consumption of water resources in the school building.  
• Management of Energy and operational systems to ensure the highest levels of operational efficiency of the building. |
Standards of planning and design of high-efficiency basic education schools in Cairo

The standards of design of high-efficiency basic education schools are divided into the following 16 standards: Designing and planning the masterplan, efficiency of acoustic comfort, thermal comfort, Visual comfort, natural and artificial lighting efficiency, efficiency of the indoor air quality of the spaces, efficiency of the external envelope design, efficiency of ventilation of the building (natural ventilation - HVAC systems), sustainability for Materials and Operational Systems, energy consumption efficiency analysis, efficient use of materials and products in the building, efficiency of the plan of (implementation - testing - maintenance) of the school building, building life cycle cost analysis, water Use Efficiency (WBDG, 2013; Myrsalieva, N., 2012; Amann, J.et al, 2003; NIST, 2001; Seep, B. et al, 2000; Kincaid, J.et al ,1995; Egan, M. D.,1983; Evans, M., 1980; Markus, T. et al., 1980)

Energy Sustainability within the School Building

Studying and determination of the requirements for applying renewable energy technologies in the school building, whether solar or wind energy, in schools in Cairo Region - Monitoring the impact of this application on the rates of reducing energy consumption and the building life cycle cost, as well as the educational and cultural aspects for students and society in general [Lackney, J. A., 1999].

An analytical study of the research case to redesign the external envelope of the building of a typical governmental school in Cairo

This model has been chosen because it is a typical regular model applied to all regions and geographic boundaries of the Cairo region without taking into consideration the conditions and determinants of the site. To evaluate the school design and operational efficiency in the post-occupancy phase, a method of analysis and evaluation was applied, which is divided into two parts: Part I: Documentation and monitoring of data stage, Part II: modification of the building external envelope to reduce energy consumption and improve the efficiency of thermal performance inside the building through the use of design builder program stage [Shaghayegh, 2013].

Criteria for selecting a case study

The Tabari Al Hijaz School- Heliopolis – Cairo has been chosen as it is one of the typical governmental schools established in more than location within the boundaries of Cairo. The field study and personal interview with students and teachers indicated that the architect did not achieve thermal, visual and acoustic comforts within the internal spaces. Due to the economic conditions of Egypt, all governmental schools do not use mechanical means for air conditioning to achieve comfort within the internal spaces of the classrooms.
Locating a case study site

Cairo was chosen to conduct the field study in the Arab Republic of Egypt because it is the capital of Egypt, with a population of 9.1 million, 10.6% of the population of Egypt, which is growing very rapidly. It also contains the largest number of educational buildings in Egypt.

The building is located at the following coordinates, 30° East 30° North. The building lies in a vital location in Al Hijaz Square – Heliopolis. Al Hijaz Square is one of the most important areas in Heliopolis district and also the most important in Cairo. Moreover, the school is located on the junction of three streets from the north, west and south.

Climatic analysis of Cairo

Cairo is the capital of Egypt; it lies at a longitude of 31° East and latitude of 30° North. It is classified as a hot arid region. According to the Egyptian Organization for Energy Conservation and Planning (EOECP), Cairo is classified as a Semi Desert zone within the seven climate classification zones of Egypt. The Semi desert zone has an average annual temperature of 22.2°C, with a maximum monthly average temperature of 34.2°C in August and minimum monthly average temperature of 10.2°C in January. Extreme temperature in Cairo may reach a maximum of 44°C and an extreme minimum of 3°C. As for diurnal ranges, it has a monthly mean difference of 12-17°C with a mean of 14°C in summer and 13°C in winter.

The monthly average relative humidity is 57.75%, with a maximum monthly average of 68% in January and a minimum monthly average of 44% in May.

The Khamsin winds hit Cairo in spring time, which are southern hot winds accompanied with sand and dust. Whereas, the preferable wind blows from North West.

Being classified as hot and arid, Cairo has a recorded maximum direct solar radiation in the month of July of 597w/m² and a minimum of 304w/m² in January.
Tabri School – Cairo

Type of building: Educational building  
Owner: Ministry of Education  
Location: Al Hijaz Square - Heliopolis - Cairo - Egypt

The ground floor area of the school building is 1012 m² and the total area of the floors is 4048 m², where the building consists of a ground floor and three typical floors.

The building was oriented towards the North-east due to the conditions and location determinants. The school classrooms were oriented North-east and the corridor between the classrooms was oriented South-west at a 45° angle. The school was built according to a structural system based on reinforced concrete, the use of red bricks for the construction of external and internal walls, the use of glass and wood for windows, the use of terrazzo tiles for the floors of the spaces inside the building and the use of cement tiles for the roof of the school building.

The school consists of the followings:

- An administrative building consists of a ground floor only.
- The old educational building consists of a ground floor and three typical floors (case study).
- The modern educational building consists of a ground floor and three typical floors.
**Building Simulation**

The design builder program was applied to the secondary school building to calculate the energy consumption, then several different alternatives were put in place to modify the design of the external envelope of the building and to modify the types of lighting used in order to reduce energy consumption to increase the efficiency of environmental performance of the building.

![Energy consumption throughout the year](image)

Table 2. Physical Characteristics of wall components

<table>
<thead>
<tr>
<th>Component</th>
<th>Layer L cm</th>
<th>Conductivity k watt/m. c°</th>
<th>Density p kg/m³</th>
<th>Specific C (jol/kg. c°)</th>
<th>Resistance R (m². c°/watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Cement mortar</td>
<td>2</td>
<td>0.93</td>
<td>2000</td>
<td>750</td>
<td>0.021</td>
</tr>
<tr>
<td>2-Solid Cement brick</td>
<td>25</td>
<td>1.4</td>
<td>2000</td>
<td>840</td>
<td>0.178</td>
</tr>
<tr>
<td>3-cement mortar</td>
<td>2</td>
<td>0.93</td>
<td>2000</td>
<td>750</td>
<td>0.021</td>
</tr>
<tr>
<td>U-value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.51 (W/m². K)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.398 (m². K/ W)</td>
</tr>
</tbody>
</table>

Table 3. Physical Characteristics of roof components

<table>
<thead>
<tr>
<th>Component</th>
<th>Layer L cm</th>
<th>Conductivity k watt/m. c°</th>
<th>Density p kg/m³</th>
<th>Specific C (jol/kg. c°)</th>
<th>Resistance R (m². c°/watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Gypsum Plastering</td>
<td>2</td>
<td>0.4</td>
<td>1000</td>
<td>1000</td>
<td>0.05</td>
</tr>
<tr>
<td>2-reinforced concrete</td>
<td>26</td>
<td>2.3</td>
<td>2300</td>
<td>1000</td>
<td>0.11</td>
</tr>
<tr>
<td>3- expanded polystyrene</td>
<td>5</td>
<td>0.035</td>
<td>35</td>
<td>1400</td>
<td>1.42</td>
</tr>
<tr>
<td>4- Preference Concrete</td>
<td>7</td>
<td>0.72</td>
<td>1850</td>
<td>840</td>
<td>0.096</td>
</tr>
<tr>
<td>5- sand</td>
<td>5</td>
<td>0.3</td>
<td>1500</td>
<td>800</td>
<td>0.167</td>
</tr>
<tr>
<td>6-cement tile &amp; mortar</td>
<td>5</td>
<td>1</td>
<td>1900</td>
<td>840</td>
<td>0.05</td>
</tr>
<tr>
<td>U-value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.47(W/m². K)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.083(m². K/ W)</td>
</tr>
</tbody>
</table>

Table 4. Optical properties of the glass used in the case study.

<table>
<thead>
<tr>
<th>Type of glass</th>
<th>SHGC</th>
<th>U-value</th>
<th>VT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single glass 6mm</td>
<td>0.81</td>
<td>6.12</td>
<td>0.88</td>
</tr>
</tbody>
</table>

**Base case simulation results**

All data and information for the site, such as the occupancy periods of the building during the day and the year, the construction systems, the specifications of the external envelope and the internal spaces, the nature of furniture and the activities being carried out within these spaces. The used electrical devices have been entered to the design program to study the current state of energy consumption throughout the year.
After studying the current situation and determining the amount of electrical energy consumed inside the building, we proposed some alternatives to improve the efficiency of the building and reduce the use of electric energy. Some of the inputs to the Design Builder program are changed. The effect of changing these inputs on the efficiency of the building and the reduction in electrical energy consumption is studied.

**Suggested solutions to reduce energy consumption in the building**

**The first alternative (using a double wall with a gap)**

The first alternative is to change the wall type to a double wall with a 5cm vacuum thermal insulation.

1. Cement mortar, layer 2 cm, R=0.024 m².c/watt
2. Light sand brick, layer 25 cm, R=1.92 m².c/watt
3. Expended polystyrene, layer 5 cm, R=1.82 m².c/watt
4. Light sand brick, layer 12 cm, R=1.92 m².c/watt
5. Cement mortar, layer 2 cm, R=0.024 m².c/watt

Quantity of electricity consumed by the building according to the first alternative during one year = 190525kWh after saving electricity consumption of 37073Kwh compared to the current situation by reducing the consumption by 16%.

**The second alternative: Using double blue glass in the transparent part of the building**

The effect of using double blue glass (production of SAINT-GOBIN) in the transparent part of the building on the energy consumption.

- Amount of electricity consumed by the building according to the second alternative during one year = 195325kWh.
• The amount of electricity consumption according to the second alternative = 195325Kwh after saving electricity consumption 32273Kwh compared to the current situation by rationalizing the consumption by 14%.

**The third alternative: Return-air ducted**

This alternative replaces the current situation light units with return-air ducted light units, which reduce the heat emission from the light units, so that the heat is drawn out of the space. This helps to reduce the amount of electrical energy consumed. Figure 14 shows how to draw that hot air.

• Quantity of electricity consumed according to the third alternative of the building during the year = 202014kWh

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Blue (#2) 12mm Air Space 6mm Clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>VISIBLE LIGHT</td>
<td></td>
</tr>
<tr>
<td>Transmission (%)</td>
<td>49</td>
</tr>
<tr>
<td>Reflection out (%)</td>
<td>8</td>
</tr>
<tr>
<td>Reflection in (%)</td>
<td>11</td>
</tr>
<tr>
<td>SOLAR ENERGY</td>
<td></td>
</tr>
<tr>
<td>Transmission (%)</td>
<td>30</td>
</tr>
<tr>
<td>Reflection out (%)</td>
<td>8</td>
</tr>
<tr>
<td>U-VALUE (W/M2. K)</td>
<td>1.80</td>
</tr>
<tr>
<td>G Value</td>
<td>0.36</td>
</tr>
<tr>
<td>Shading Coefficient</td>
<td>0.42</td>
</tr>
<tr>
<td>1st Lite Price (L.E/sqm)</td>
<td>165</td>
</tr>
<tr>
<td>2nd Lite Price (L.E/sqm)</td>
<td>35</td>
</tr>
<tr>
<td>Both Lite Price(L.E/sqm)</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 5. physical Characteristics of glass.

![Figure 11. (left) The energy saving percentage according to the second alternative 14%](image1.png)

**Figure 12. (Right) The quantity of electricity consumed in the building in the second alternative**

![Figure 13. (Left) How the return-air ducted system appears in the ceiling](image2.png)

**Figure 14. (Right) Shows how to draw hot air into the Return air ducted system**
The amount of electricity consumption according to alternative three = 202014Kwh after saving electricity consumption of 25584Kwh compared to the current situation by reducing the consumption by 11%.

The fourth alternative (Change the type of light source and use T5 (Ø16mm))

This alternative depends on changing the type of light source from the current situation and replacing it with a light source T5 (Ø16mm) Fluorescent lamp, triphosphor, high-frequency control gear. It helps to reduce energy consumption, which reduces the effect of the school building on the surrounding environment and makes it more environment-friendly.

• Quantity of electricity consumed according to the fourth alternative of the building during the year = 169551KWh
• The amount of electricity consumption according to alternative four = 169551KWh after saving electricity consumption of 58047Kwh compared to the current situation by reducing the consumption by 25%.

Figure 15. (left) The energy saving percentage according to the third alternative 11%
Figure 16. (Right) The amount of electricity consumed in the building in the third alternative

Figure 17. (left) The energy saving percentage according to the fourth alternative 25%
Figure 18. (Right) The quantity of electricity consumed in the building in the fourth alternative
The fifth alternative (accumulation of all changes made in the previous alternatives in one alternative)

This alternative is a combination of all the previous alternatives in one alternative, where all of these changes are put together: Wall thickness - Type of glass - Type of lighting unit - Type of light source.

- By analysing the data, it was found that the quantity of electricity consumed in the fifth alternative of the building during the year = 160343 kWh
- The amount of electricity consumption in Alternative five = 160343Kwh after saving electricity consumption of 67255Kwh compared to the current situation by reducing the consumption by 30%.

Comparison between the current Situation with the five alternatives and the chart shows the following

- The quantity of electricity consumed in the first alternative during the year = 190525kWh with electricity consumption saving of 37073Kwh compared to the current situation, with a reduction percentage of 16%.
- The quantity of electricity consumed in the second alternative during the year = 195325kWh with electricity consumption saving of 32273Kwh compared to the current situation, with a reduction percentage of 14%
- The quantity of electricity consumed in the third alternative during the year = 202014kWh with electricity consumption saving of 25584Kwh compared to the current situation, with a reduction percentage of 11%
- The quantity of electricity consumed in the fourth alternative during the year = 169551kWh with electricity consumption saving of 58047Kwh compared to the current situation, with a reduction percentage of 25%

When a comparison was made between the current situation and alternative five, it was found that the electricity consumption in the current situation is 227598Kwh, the amount of electricity consumption in alternative number five is 160343Kwh, which means electricity consumption saving of 67255Kwh, with a reduction percentage of 30%.
Results

High-efficiency schools are buildings that provide a healthy educational environment (for students and teachers). It helps to reduce energy consumption, as well as operating and maintenance expenses of the building, while applying the principles of sustainability regarding “energy - water - the use of materials”. The school building itself can be used as an educational tool to remove environmental illiteracy for students, teachers and the society.

The design and assessment approach for high efficiency schools is a successful framework for upgrading the design standards of schools in Egypt and an appropriate system for evaluating the design and operational efficiency of schools in Egypt in general.

The proposed design and evaluation criteria for high efficiency basic education schools in the Cairo Region are in line with the green assessment systems for schools, which increases the design and operational efficiency of schools in the Cairo Region in particular and in the rest of the climatic regions in Egypt in the near future when it is applied on the rest of the republic regions according to the circumstances associated with each climatic or planning region.

The design of a high efficiency basic education school buildings is neither expensive nor complex, but requires an understanding, awareness and study of all the direct and indirect effects of high efficiency school design standards and their impact on the design and operational efficiency of the school building in general.

The designer has a significant impact in the process of providing thermal and visual comfort within the interior spaces.

There is not yet a typical school assessment method in Egypt to evaluate schools in terms of efficiency (design efficiency, operational efficiency, adaptation to the environment, application of sustainability principles, conservation of energy consumption, operating and maintenance costs).
Basic education school building design Standards in Cairo and the rest of the Republic are acceptable as far as producing a traditional school building is concerned. However, as the frequency of crises and contemporary and future challenges in the fields of (energy, water, economy) has increased this traditional building will become a hotbed of problems and a burden for the state and the competent ministries. If these entities try to solve some of these problems, it will be a temporary solution, which does not tackle the root of the problem in the long term.

The applied study has shown that it is possible to redesign the external envelope of the school building in order to achieve the thermal comfort and energy consumption reduction to reach a high efficiency school building.

References


Energy performance analysis in early design stages through parametric simulations: case study of a mixed-mode building

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Abstract: Building Energy Simulation (BES) tools have an important role in early design stages, since they include energy performance parameters in the decision-making process. However, processing a large number of simulations can be unfeasible, costly and time-consuming, especially when architectural conceptual design phase is considered. Therefore, the development of computer codes can facilitate this process. The aim of this work was to develop a code in Python language, which could perform parametric analyses of a mixed-mode office building in EnergyPlus, considering random variables related to its design process. Ten parameters were chosen, including materials properties, envelope dimensions and geometry related variables. Ranges of variation for each variable were settled according to practical restrictions resultant from the building industry. Results showed that the code operates properly and can easily be used to create a set of design scenarios, proving to be a useful tool to architectural designers. A specific case study is presented, in order to illustrate the application of the method and its potential benefits in an integrated design process.

Keywords: Python, Parametric analysis, EnergyPlus, Early design stage

Introduction

Building Energy Simulation (BES) is essential to predict energy consumption in the early stages of building design, since design decisions, at these stages, have a major impact on final building performance and costs (Østergård et al, 2016). The solutions for the building envelope, in early design stages, are numerous and involve complex building physics, which makes it difficult to achieve a proper low energy design without the help of simulations. Hence, the prediction of building energy performance associated with different architectural design parameters has appeared in many recent studies, such as Charisi (2017), Ferrara et al (2017), Banihashemi et al (2015) and Ihara et al (2015).

Despite the recent studies, in practice the building orientation, fenestration and construction materials, designed by architects during the concept design stage, usually have little or no support of BES (Picco et al, 2014). Although BES is a useful method to compare design options, it is still mostly used only to check code compliance, benchmarking or green building certification requisites, in the final steps of the design process, after the architectural decisions were made (Picco et al, 2014). One of the reasons is that popular energy simulation tools, such as EnergyPlus, IES-VE, DesignBuilder, eQUEST, are complex simulation engines and designers find it difficult to fully exploit them (Punjabi and Miranda, 2005). Even being an important step in building performance evaluation, conducting energy simulation analyses in early design stages requires substantial time, resources, and technical expertise (Hygh et al, 2012).

Since only less than 8% of the existing simulation tools listed on the website of U.S.
Department of Energy have the potential to be used by architects in early design (Batueva and Mahdavi, 2015), developing codes to help processing parametric analyses and, consequently, facilitate the use of complex simulation tools are welcome. Asadi et al (2014), for example, developed a model to predict and quantify energy consumption in the early stages, considering building materials, their thickness, building shape, and occupant schedule as design variables, for commercial buildings located in Houston, United States. Hygh et al (2012) used multivariate regression to evaluate the impact of 27 building parameters relevant to the early design stages, including geometry and envelope thermal properties variables, for a medium-sized, rectangular office building located in four different climates of the United States. Elbeltagi et al (2017) developed a coupling parametric software with energy simulation tools and presented a simplified visualization tool for estimating residential buildings’ energy consumption located in Egypt, during early design stages.

Considering this scenario, the aim of this work is to assist the use of BES tools in the decision-making process during early design stages. Therefore, this paper presents a coupling code with EnergyPlus software, created to develop parametric analyses in an automated way, to be used to analyse the energy performance of mixed-mode office buildings. The research is focused on the code development, given that its main aim is to serve as a basis to architectural designers, in order to help them investigating architectural problems. The mixed-mode ventilation (MMV) system is a way of combining the best features of naturally ventilated and air-conditioned buildings (Brager, 2006). This is a relatively new research subject; there are no standards for its operation or for its control strategies (Nicol, 2017). In addition, there still isn’t a complete guide on how to simulate or even design such buildings (Salcido et al, 2016), which makes their modelling in simulation programs an even more challenging task.

Method

This paper presents the development of a code created in Python language to perform parametric simulations through EnergyPlus Building Energy Simulation (BES) software. The code is open source and can be found in the following link: http://www.iau.usp.br/laboratorios/lca/index.php/trabalhos-conforto. Python is a multiplatform language that runs on several operating systems, including Windows, Linux, and Mac. Its syntax is clear, objective and simple, still being a robust and powerful tool, with a big diversity of libraries. It is also considered, amongst several authors, the best choice to carry out scientific applications by scientists and engineers (Menezes, 2014; Oliphant, 2007; Severance, 2009). EnergyPlus is a simulation program validated by ANSI/ASHRAE Standard 140 (ASHRAE, 2014). Its physics base allows it to perform thermal and energy performance analyses through sets of envelope thermal properties, occupancy patterns, thermal loads and others (EERE, 2014).

The code was written to modify key parameters’ values of several EnergyPlus input data files (.idf extension) and to automate the data processing of a group of simulation models of a mixed-mode office building. The Monte Carlo Analysis (MCA) was chosen to randomly select the values for each input parameter, in order to compose a group of different input data files. The process can be repeated as many times as necessary to compose the sample, using a unique set of inputs on each occasion (Lomas and Eppel, 1992). The range and precision of each key parameter are determined by the user. Results from a large number of simulations are then coupled and organized in comma separated values (csv) spreadsheets and can be
analysed by the user. In order to demonstrate how the code works, this paper also presents a case study of a mixed-mode office building located in the city of Sao Paulo, Brazil.

**Python code for parametric simulations**

All necessary files to perform and postprocess the parametric simulations are located in a folder called ‘parIDF’ (Figure 1). The contents of ‘parIDF’ are the following:

- File ‘paridf.py’: this is the code that performs the parametric simulations.
- Files ‘generateResults.py’ and ‘aggregateResults.py’: these are scripts created in order to postprocess the results.
- Folders “classes”, “files” and “outputs”: include various files and codes that are used or generated by the other files (‘paridf.py’, ‘generateResults.py’ and ‘aggregateResults.py’). Some of these files contain input data and must be created or customized by the user.

The code ‘parIDF’ can be used from any computer terminal and processed both from Linux or Windows operating systems. However, while in Windows the EnergyPlus program must be run externally, in Linux the EnergyPlus program is automatically run for all parametric combinations.

The ‘parIDF’ code was developed to be as generic as possible, so there are customizable parts that can be adjusted by the user (‘.json’ files extension, located in the ‘files’ folder, Figure 1). For example, in the file ‘config.json’, all information regarding the simulations and the parametric variations should be defined, such as number of simulations (‘quantity’); weather file name; pattern of change, ranges and precision of variable parameters, etc. (Figure 2). The user must also create an EnergyPlus input data file (.idf file, also in the “files” folder, Figure 1) to be used as a base case file for the generation of the new idf’s.

```
1 {
2     "quantity": 100,
3     "path": {
4         "base": "/home/.../parIDF/files/casestudy.idf",
```
"destination": "/home/.../parIDF/output",
"weatherFilename": "BRA_SP_Sao_Paulo.epw",
"parameterFile": "parameter.csv",
"filename": "file"
},
"variables": {
"WindowMaterial:SimpleGlazingSystem": {
  "identifiers": {
    "glazing": {
      "Solar Heat Gain Coefficient": {
        "alg": "MonteCarlo",
        "parameters": {
          "min": 0.20,
          "max": 0.90,
          "precision": 0.01
        }
      }
    }
  },
  "Zone": {
    "Z Origin {m}": {
      "alg": "Predefined",
      "parameters": {
      ...
    }
  }
},
...(Figure 2)

After generating these idf files according to random variations of the variable parameters within the Monte Carlo framework, the ‘parIDF’ code runs the EnergyPlus and also creates an output data file. This output data file contains a comma separated value (csv) file, which lists all performed variations (‘parameter.csv’) and the simulations outputs for each idf file. The ‘parIDF’ code is object-oriented, allowing the use of classes and native libraries (Severance, 2009). The main classes, located in the folder “classes”, are defined as ‘idfobject.py’, ‘idfset.py’, ‘main.py’ and ‘montecarlo.py’ (Figure 1).

The EnergyPlus idf file syntax considers that all parameters (ex: ‘Solar Heat Gain Coefficient’), belong to an object (ex: ‘glazing’), and are part of an object group (ex: ‘Window Material: Simple Glazing System’). Thus, the ‘idfobject.py’ class receives the string from each parameter and its corresponding inputs, saving this information in a list, in order to create new idf’s. The ‘idfobject.py’ class, though, manipulates each parameter of an object, through the use of native library importing (‘import re’), which are defined as regular expressions (‘Regex’) and are used to develop file analyses and pattern identification (Figure 3).

def getParameterValue(self, string):
    regex = re.search('(.+)[,]', string)
    found = ''
    if regex:
        found = regex.group(1)
    return found
...(Figure 3)

The ‘idfset.py’ class is responsible for analysing the base case idf, identifying the groups and determining an ‘idfobject.py’ class for each group, also using a ‘Regex’ expression. This class saves the groups in a structured way, providing functions to find each parameter from its name, and rebuilding the idf file to create the parametric files. The ‘main.py’ class joins the
above-mentioned classes (‘idfobjecty.py’ and ‘idfset.py’), also calling the necessary class to perform the parameters’ variations. The variation is indicated by the ‘method’ class. These are classes with generic algorithms to process the parameters, and must be created and defined by the user. The ‘Monte Carlo’ method class was created through the mathematical function ‘Random’ from the native library, which generates evenly distributed random values. A range of values (‘min’, ‘max’) and each value’s precision (‘precision’) must be specified by the user, ensuring that similar values will not occur (ex: 0.001 and 0.0010000001). The code also allows the creation of other algorithms, according to the user needs, by creating independent ‘method’ classes and calling them in the ‘config.json’ file.

The code was configured to allow performing parametric variations of variables related to architectural early design stages, which are: envelope design (window-to-wall ratio, solar orientation, floor height, exterior shading devices), external walls’ thermal properties (thermal capacity, thermal transmittance, solar absorptance), windows (glazing solar heat gain coefficient, window opening effective area), and interior blinds. One limitation of the developed code is its inability to analyse more than one space geometry, which means that the geometry configuration of the room (length, width and height) are fixed input entries.

Two scripts are responsible for organizing the outputs. The ‘generateResults.py’ script analyses the csv files generated from a group of simulations, located in the ‘outputs’ folder, and creates a new csv file containing the columns defined by the user within the configuration file (‘resultConfig.json’), allowing the user to select and visualize an entire group of simulations in the same spreadsheet (Figure 4). The ‘aggregateResults.py’ script allows the user to configure a ‘.json’ file to create a spreadsheet to perform calculations defined by the user, such as sum or maximum number, by using selected columns from the csv file (Figure 5).

```json
1 {
2   "path": {
3     "source": "/home/.../parIDF/output/output/csv",
4     "destination": "/home/.../parIDF/output",
5     "filename": "file"
6   },
7   "results": {
8     "HVACIdeal.csv": {
9       "meter": false,
10      "columns": [
11         "ZN1 IDEAL LOADS AIR SYSTEM:Zone Ideal Loads Supply Air Total Cooling Rate [W](Hourly)"
12       ]
13     }...
```

Figure 4. ‘resultConfig.json’

```json
1 {
2   "path": {
3     "source": "/home/.../parIDF/output",
4     "destination": "/home/.../parIDF/output"
5   },
6   "files": {
7     "HVACIdeal.csv": {
8       "columns": {
9       "ZN1 IDEAL LOADS AIR SYSTEM:Zone Ideal Loads Supply Air Total Cooling Rate [W](Hourly)": {
10       "values": [
11       "SUM"
12       ]
13     }...
```

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Case study

A case study of a room within a mixed-mode office building is presented to demonstrate the code operation. Considering the early design stage, first it would be necessary to define a conceptual design, that means, to think of a model with fixed parameters and from it the variations of design parameters that may impact its performance. The base case model was defined based on a large dataset containing design parameters of mixed-mode office buildings located in the city of Sao Paulo, Brazil (Neves et al, 2017). Figure 6 presents the geometry and Table 1 presents the model’s input fixed parameters and values.

![Figure 6. Base case model](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office room area</td>
<td>40 m² (5 m x 8 m)</td>
</tr>
<tr>
<td>Ceiling height</td>
<td>2.7 m</td>
</tr>
<tr>
<td>Number of floors</td>
<td>12</td>
</tr>
<tr>
<td>Natural ventilation strategy</td>
<td>cross ventilation (adjacent facades)</td>
</tr>
<tr>
<td>Glazing U-value</td>
<td>5.67 W/(m²K) (single pane glazing)</td>
</tr>
<tr>
<td>Slab U-value</td>
<td>3.75 W/m²K</td>
</tr>
<tr>
<td>Internal loads - people</td>
<td>14 persons/100m² (ABNT, 2008)</td>
</tr>
<tr>
<td>Internal loads - lights</td>
<td>9.7 W/m² (BRASIL, 2009)</td>
</tr>
<tr>
<td>Internal loads - equipment</td>
<td>10.7 W/m² (ABNT, 2008)</td>
</tr>
<tr>
<td>Schedule</td>
<td>weekdays from 8 am to 6 pm</td>
</tr>
<tr>
<td>Wind pressure coefficient</td>
<td>surface average calculation (EnergyPlus default)</td>
</tr>
<tr>
<td>Discharge coefficient</td>
<td>0.6 (ASHRAE, 2005)</td>
</tr>
<tr>
<td>Infiltration</td>
<td>2.5 L/s.person + 0.3 L/s.m² (ABNT, 2008)</td>
</tr>
</tbody>
</table>

Ten variable parameters were chosen based on their influence over the annual energy demand of a mixed-mode office building (Bajenaru et al, 2016; Engelmann et al, 2014; Corgnati and Kindinis, 2007; Chang et al, 2004). Ranges of variation were set based on feasible values from the building industry. Table 2 presents the variable parameters and their minimum and maximum values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base case model input</th>
<th>Minimum</th>
<th>Maximum</th>
<th>EnergyPlus object - Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar orientation (azimuth angle)</td>
<td>270°</td>
<td>0°</td>
<td>315°</td>
<td>Building and Airflow Network Simulation Control</td>
</tr>
<tr>
<td>Number of floors</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>Zone</td>
</tr>
<tr>
<td>Window-to-wall ratio (WWR)</td>
<td>30%</td>
<td>10%</td>
<td>70%</td>
<td>Fenestration Surface Detailed</td>
</tr>
</tbody>
</table>
The ASHRAE 55-2013 adaptive comfort model (ASHRAE, 2013) was used to control the mixed-mode system operation, determining a thermal comfort zone that satisfies 80% of occupants. The cooling system was modelled using an ideal air conditioning system. Natural ventilation was modelled using the Airflow Network engine, allowing the approximation of pressure-driven air exchanges with the outdoor environment, which accounts for cross-ventilation. The Energy Management System (EMS) functionality in EnergyPlus was implemented to control the opening of windows.

**Python code adjustments for the case study**

To run the code, the customizable parts of the `.json` files should be configured. Therefore, to perform this case study, the variable parameters (Table 2) were configured within the ‘config.json’ file. A simple Monte Carlo variation algorithm was used to set the variation of the independent parameters, as shown in Table 3. For those parameters whose variations are linked to other EnergyPlus objects, algorithms were created to represent this relationship. As an example, the algorithm called ‘predefined’, which randomly chooses a variable among predefined variables, was used to set up the solar orientation, which depends on ‘North Axis’ and ‘Airflow Network Simulation Control’ entries.

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Distribution</th>
<th>EnergyPlus input</th>
<th>Min</th>
<th>Max</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar orientation (azimuth angle)</td>
<td>Discrete</td>
<td>Building (North Axis) and Airflow Network Simulation Control (Azimute Angle of Long Axis of Building)</td>
<td>0, 45, 90, 135, 180, 225, 270, 315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of floors</td>
<td>Discrete</td>
<td>Zone (Z origin)</td>
<td>2.7, 5.4, 8.1, 10.8, 13.5, 16.2, 18.9, 21.6, 24.3, 27, 29.7, 32.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WWR</td>
<td>Continuous</td>
<td>Fenestration Surface Detailed (Vertex 1 Z-coordinate and Vertex 4 Z-coordinate)</td>
<td>1.02</td>
<td>2.67</td>
<td>0.01</td>
</tr>
<tr>
<td>Exterior shading device</td>
<td>Continuous</td>
<td>Shading Overhang Projection (Depth as Fraction of Window/Door Height) and Shading Fin Projection (Left Depth as Fraction of Window/Door Width and Right Depth as Fraction of Window/Door Width)</td>
<td>0.01</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Internal blinds</td>
<td>Discrete</td>
<td>Window Material Blind (Front)</td>
<td>0, 0.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Once the variable parameters settings were defined, a total amount of 100 simulations was set up in the ‘config.json’ file and the output scripts, ‘generateresult.py’ and ‘agregateresult.py’ were adjusted within the ‘resultConfig.json’ and ‘aggregateConfig.json’ files, to provide the following outputs: Zone Ideal Loads Supply Air Total Cooling Rate [W] hourly (HVACideal.csv) and total sum (aggregateHVACideal.csv).

Results and discussion

The output data files created by the Python code contain the necessary information to easily analyze the outputs from the simulation set: the ‘parameter.csv’ file lists all performed variations within each .idf file, the ‘HVACideal.csv’ file presents the hourly output data of each .idf file, and the ‘aggregateHVACideal.csv’ file presents the annual sum output data of each .idf file.

Frequency histograms (Figures 7 and 8) were used to verify if the precision adopted for each variable parameter’ distribution range (Table 3) and the total amount of simulations (100) were adequately set. Figure 7 shows the results for a continuous variable, solar absorptance; and Figure 8 shows the results for a discrete variable, solar orientation. The standard deviation (9.8 for solar absorptance and 2.9 for solar orientation) shows a non-uniform distribution within the sample, which could be improved by raising the number of simulations, raising the precision, and/or reducing the distribution range.

The ‘aggregateHVACideal.csv’ file was used to generate charts and analyze the results. Considering the simulation set used in this case study, the variable parameters ‘window...
opening effective area’ and ‘solar heat gain coefficient’ showed the highest impact over the annual thermal loads results. Figures 9 and 10 show the results for the ‘window opening effective area’ variation, through two different chart types. It can be observed that, as the effective area increases, the annual thermal loads decreases and, from 55% up, the variation of other parameters is less prominent over the final result, with a $R^2$ value of 0.26. These results emphasize the importance of the window opening effective area on the natural ventilation performance of a mixed-mode office building. It also shows that the base case model input (27%), which represents a large dataset of mixed-mode office buildings from Sao Paulo city, is lower than the best range. The impact of the effective area over the energy performance of mixed-mode office buildings is a subject that requires further analyses, since no specific studies were found in the literature, beside Santesso (2017).

![Figure 9. Window opening effective area (scatter plot chart)](image)

![Figure 10. Window opening effective area (bar chart)](image)

Figures 11 and 12 show the results for the ‘solar heat gain coefficient (SHGC)’ variation, through two different chart types. It can be observed that, as the SHGC increases, the annual thermal loads also increase and, from 33% down, the variation of other parameters is less prominent over the final result. The impact, though, is not as strong as the window opening effective area, with a $R^2$ value of 0.18. In this case, the base case model input (0.9) is also distant from the best range.

![Figure 11. SHGC (scatter plot chart)](image)

![Figure 12. SHGC (bar chart)](image)

**Conclusion**

This paper presents a code in Python language, developed to perform energy performance parametric analyses of mixed-mode office buildings in early design stages, by using the EnergyPlus program as the computer simulation engine. Its main aim is to serve as a basis to perform in-depth investigations of architectural design aspects. The code is customizable by
the user, allowing the selection of key parameters to be modified within a simulation set, in order to verify its impact over selected output data, such as annual thermal loads. One of the code’s greatest potential is its capability to simplify the use of a complex simulation engine such as EnergyPlus during the early design stages, assisting its use to support design decisions.

It is important to highlight the limitations presented by the current code. Since it is not still fully developed, the code is not supported by a graphical interface to simplify its use and to automatically generate charts from the output data. It also does not include a set of classes, to modify the building’s geometry (room’s length, width and height), which is a complex input parameter within EnergyPlus.

Acknowledgements

The work reported in this paper was supported by Sao Paulo Research Foundation (FAPESP 2016/17691-4, 2017/04660-6 and 2016/02734-0), Brazil.

References


Climate Change Impact on Energy consumption and Thermal performance in low-income houses in Brazilian Savanna

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Abstract: Climate change has presented itself as a substantial challenge to be faced by society in the 21st century. Rising temperatures is a potential threat to ecosystems but also for humans. They directly affect buildings thermal behaviour, increasing energy consumption to maintain its users’ thermal comfort. Thus, studies on climate change related to the building thermal performance and the search for its mitigation have gained importance. This study aims to analyse the impact of climate change on thermal performance and energy consumption in low-income houses located at the Tropical Savannah climate (Aw), as well as to suggest strategies to mitigate the impact on these buildings. The study area is the city of Cuiabá, State of Mato Grosso, Brazil, located in the Brazilian Savannah Ecosystem, with tropical sub-humid climate, the second most common climate in the world. Climatic projections were designed based on the “morphing” methodology, considering the A2 scenario of the Fourth Intergovernmental Panel on Climate Change (IPCC) and time slices 2020 (2011-2040), 2050 (2041-2070) and 2080 (2071-2100). Building thermal performance and energy consumption were simulated using the EnergyPlus software. Climate change will impact the annual mean dry-bulb air temperature in the 2020s, 2050s and 2080s, increasing it by 1.5 °C, 3.0 °C and 5.9°C in relation to the base scenario, respectively. It will influence the building thermal performance, increasing the percentage of annual cooling degree-hours from 51.8% in 1961-1990 to 88.6% in 2080s, whilst the heating degree-hours will reach 0%. In turn, the building energy consumption will increase by 43.6% in 2080s. Based on these results, it is essential to adopt passive strategies to mitigate the impact of climate change, focusing to improve building efficiency and thermal comfort, collaborating with vulnerable communities to absorb future climate impacts.

Keywords: Climate change, thermal performance simulation, energy efficiency simulation, Energy Plus

Introduction

In recent years, climate change has been the subject of many studies worldwide, and several organizations have gathered data about it in order to understand its risks to humanity (IPCC,
Among the effects of climate change are severe changes in temperate countries, which have suffered from hot summers (Aebischer, 2007), as well as the increase in mean air and ocean temperatures, which has caused melting polar ice caps, intensified heat waves, drought periods and has altered biological processes (Marengo, 2007). Faced with this evidence, climate change is a substantial challenge to be faced by 21st century society.

The Intergovernmental Panel on Climate Change (IPCC, 2010) organizes scientific, technical and socio-economic bases related to global warming and climate change. In 2007, this organism created the Fourth Assessment Report (AR4), which states that over the last twelve years (1995-2006), eleven are among the highest temperature indexes ever registered (IPCC, 2007).

It is estimated an increase in the global average temperature ranging from 2 to 5.4°C between 1900 and 2100 (IPCC, 2007). It may result in potential threats to ecosystems but also for humans, directly affecting the buildings thermal behaviour and the users’ thermal comfort.

Buildings have been generally considered to have a lifespan of 50 years (Wan et al, 2012). Therefore, it is necessary to design them being able to withstand climate change on the next decades, in order to provide habitability conditions for its users and reduce energy demand and greenhouse gas emissions.

The object of this research is a low-income house located in a region of tropical savannah climate, which presents high air temperatures throughout the year. As a consequence of this geographic location, even when the design considers architectural bioclimatic strategies to adapt the building to its climate zone, in many periods of the year, it is necessary to use artificial conditioning system to bring back internal air temperature to the habitability criteria. Because of the predictions set by the Intergovernmental Panel on Climate Change (IPCC), it is probable that the typical meteorological day will change in the next coming decades, which makes it necessary to provide buildings with greater resilience to climate change.

Based on what was mentioned, the focus of the article is to comprehend the global warming future impact on thermal performance and energy demand of low-income houses (LIH) located at the Aw climate zones. It intends to provide the magnitude of the impact that will guide designers to absorb climate change in buildings, especially the most vulnerable communities.

**Aim**

The current research aims to analyse the impact of climate change on thermal performance and energy consumption of a single-family low-income house (LIH) located in the Savannah Tropical climate (Aw), considering the A2 emission scenario of the Fourth Assessment Report (AR4) and the time slices 2020 (2011-2040), 2050 (2041-2070) and 2080 (2071-2100). It also intends to redesign the building to mitigate the impact of climate change, considering passive strategies prescribed by the Brazilian Technical Quality Regulation for Energy Efficiency Level of Residential Buildings, since it is the Brazilian official guide for thermal efficient building.

**Literature review**

From the perspective of climate change, researchers have conducted studies to analyse the influence of climate over the buildings habitability in some regions around the world. In the literature review, it was used as an investigation parameter, studies that considered the A2
emission scenario of the Fourth Assessment Report (AR4) in its computational simulation of building thermal and energy performance. In order to gather data to compare the results obtained in this study, the literature review was divided into two groups: regional and international studies.

From the regional point of view, Invidiata and Ghisi (2016) investigated the impact of climate change on a single-family housing in three Brazilian cities (Belém, Florianópolis and Curitiba) located in the following climatic classifications: Tropical Rainforest (Af), Humid subtropical climate (Cfa) and Temperate Highland (Cfb), respectively. It was used the Climate Change World Weather Generator tool (CCWorldWeatherGen) for the generation of future weather data and EnergyPlus Software for building thermal performance simulation. It was observed that in 2080s, average dry bulb temperatures will increase by about 4.6°C in Curitiba, 3.6°C in Florianópolis and 5.1°C in Belém. Consequently, there will be a large increase in energy demand for cooling and decrease for heating demand. It is noteworthy that in the city of Belém, the cooling energy demand will increase about 20% every decade.

Triana, Sassi and Lamberts (2016) evaluated the effects of climate change on low-income houses in the cities of São Paulo and Salvador, with Cwb and Af climatic classifications, respectively. It was used the Climate Change World Weather Generator (CCWorldWeatherGen) tool to create future weather data for the 2020s and 2050s time slices and the Energyplus software to simulate building thermal performance. The heating and cooling degree hours were estimated, as well as the building energy consumption. Results indicated that there will be an increase in the average dry bulb temperature in 2050s of 3°C and 2°C, in São Paulo and Salvador, respectively. In addition, the annual energy consumption for cooling will increase from 760 kWh/m² to 1825kWh/m² in São Paulo and from 3675 kWh/m² to 5040 kWh/m² in Salvador in the same period.

Casagrande and Alvarez (2013) concluded that the impacts of climate change will directly influence on residential buildings and its users. The performance of eight commercial buildings was investigated in the city of Vitória (ES), with Tropical Monsoon Climate type (Am), for the 2020s, 2050s and 2080s time slices. It was used the CCWorldWeatherGen tool to generate weather data and the DesignBuilder software for building simulation. The energy consumption of the buildings models, considering the use of artificial cooling system, lighting and equipment, will suffer an average annual increase of 10%, 17% and 26%, in 2020s, 2050s and 2080s, respectively.

In the scope of international studies, Radhi (2009) investigated the impacts of climate change on the city of Al-Ain, United Arab Emirates (Bwh climate classification). It was used the Irradiation Data (MeteoNorm) software to analyse the increase of air temperature and energy consumption in residential buildings. The mean air temperature increased 5.9°C between the periods of 1961-1990 and 2100. The annual cooling energy consumption, in turn, suffered an elevation of 23.5% in 2100.

Song and Ye (2017) studied the effect of climate change on residential buildings in Guangdong Province, Southern China, in order to indicate paths for possible mitigation. The CCWorldWeatherGen tool and the Transient System Simulation software (TRNYSYS) were used to identify climate-induced impacts. It was found a 3.4°C increase in the mean air temperature of the region and a 25% annual increase in energy consumption for the 2080s.

Wang, Liu and Brown (2017) evaluated the impacts of climate change on a commercial building in five cities in the United States: Miami (Aw climate type), Phoenix (Bwh climate type), Los Angeles (Csa climate type), Washington (Cfa climate type) and Akron (Dfa climate type). For the simulation, the CCWorldWeatherGen tool and EnergyPlus software were used.
Results showed an increase in total building annual energy consumption of 12.8% in Miami; 14.0% in Phoenix; 10.7% in Los Angeles, 4.0% in Washington DC and 3.7% in Akron, from the baseline period (1961-1990s) to the 2080s.

Based on the previous studies it is possible to realize that climate change will affect air temperature, increase cooling demand and reduce heating demand. Therefore, the knowledge of climate change impacts on buildings and its effects on energy consumption are important, in order to design passive design strategies to guarantee the users’ habitability in the current period as well as for future projections.

Materials and Methods

The nature of this research is qualitative and developed considering a base scenario approach (1961-1990), which was built on primary and secondary data. By this actual state, it is possible to construct a tendency or desirable future scenario (SERRA, 2006).

The methodology is divided into four stages: I) Local climate identification and generation of future climatic data; II) Building materials characterization of selected low-income house (base scenario); III) thermal performance and energy consumption analysis of the base and future scenarios; and, V) adoption and analysis of passive mitigation strategies. These steps are described below.

Local climate Identification and generation of future climatic data

The city of Cuiabá is located in the Savannah tropical climate region (Aw), characterized by two well defined seasons: dry and rainy (Machado et al., 2015). Similar climate classification can be found in several locations around the world located between the Tropics of Cancer and Capricorn. It is the second most common climate type, which comprises 11.5% of the terrestrial area (Peel et al, 2007) (Figure 1).

![Figure 1. Tropical savannah climate zones (Aw) worldwide. Font: Peel et. al, 2011, adapted by the authors.](image)

The "morphing" methodology is indicated by the Intergovernmental Panel on Climate Change (IPCC) to derive the future weather data influenced by climate change. This methodology was developed to input the climatic anomaly in the set of historical climatic data for the period 1961-1990 (base weather case), making it possible to obtain three representative future climatic data, called time-slices (Belcher et al., 2005). Some researchers
have demonstrated the complexity of developing appropriate future climate scenarios to investigate the buildings performance in the context of global warming, climate change and extreme weather events. Based on this context, Song and Ye (2017), Radhi (2009), Sabunas and Kanapickas (2017), Wang, Liu and Brown (2017), Invidiata and Ghisi, (2016), Triana, Sassi and Lamberts (2016), and Casagrande and Alvarez (2013) have adopted the "morphing" methodology to create future climate scenarios, which was applied in thermal and energy performance software aiming to analyse its influence on buildings performance.

The "Morphing" method uses three simple algorithmic operations to transform current weather data into prospective data: I) application of deviation in current hourly climatic variables by adding the average monthly variation projected in absolute values; II) an elongation of current hourly climatic variables through scheduling with the projected average variation; and III) the combination of deviation with elongation of the current hourly climatic variables. In order to consolidate algorithmic operations, the "Sustainable Energy Research Group" (SERG) of the University of Southampton in the United Kingdom has developed a tool denominated "Climate Change World Weather Generator" (CCWorldWeatherGen) (SERG, n.d.).

The CCWorldWeatherGen tool uses the Hadley Centre Coupled Model version 3 (HadCM3), which is an ocean-atmosphere coupled model with spatial resolution of 2.5° x 3.75° (latitude and longitude, in the Ecuador region). Its representation produces a resolution of 96x76 grids or 296kmx278km in latitudes 45° North or South (Gordon et al., 2000, Pope et al., 2000). This model is described in the A2 scenario of AR4 greenhouse gas emissions (IPCC, 2007), which considers moderate economic growth, high population growth, high energy consumption and a global average temperature increase ranging from 2.0°C to 5.4°C from the 1961-1990 period until the end of the century. Energy plus Weather file (EPW) for the city of Cuiabá, State of Mato Grosso, Brazil was used as the weather data. It was obtained from Solar and Wind Energy Resource Assessment (SWERA) for the 1961-1990 period (database), considered without urban density influence on the climate region due to climate change.

From this database, time-slices for periods 2020 (2011-2040), 2050 (2041-2070) and 2080 (2071-2100) were generated using the Climate World Weather File Generator (CCWorldWeatherFileGen) tool.

**Characterization of building materials**

A low-income house (LIH) widely replicated in all regions of Brazil was chosen for this study (Caixa, 2007). It is characterized as a single-family detached house in contact with the ground, with a 39.5m² of built total area, divided into living room/kitchen, bathroom and two bedrooms.

The building envelope (standard LIH) was identified and characterized by Rios (2015). The thermophysical properties of external walls, internal walls and roof were obtained from the Brazilian standard - NBR 15.220-2 (ABNT, 2015). The walls are made of ceramic six-hole hollow bricks (dimensions 0.09x0.19x0.19m) and a cement mortar layer (0.015m thick) on each side, outside painted in light colour (light beige). The pitched roof is composed of brown ceramic tiles (0.01m thick), attic space with thermal resistance equal to 0.21m²K/W, and polyvinyl chloride ceiling (PVC) (0.01m thick) (Table 1).
Table 1. Thermo-physical properties of the housing envelope (Standard LIH). Font: Guarda et al. (2018), adapted by the authors.

<table>
<thead>
<tr>
<th>Envelope</th>
<th>Materials</th>
<th>Thickness (m)</th>
<th>Thermal Resistance (m²K/W)</th>
<th>Thermal Transmittance (W/m²K)</th>
<th>Thermal Capacity (J/m²K)</th>
<th>Absorptance (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>Bright painting</td>
<td>0.40</td>
<td>2.49</td>
<td>177.30</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mortar</td>
<td>0.015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ceramic brick</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mortar</td>
<td>0.015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bright painting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>Ceramic tiles (brown colour)</td>
<td>0.01</td>
<td>0.48</td>
<td>2.08</td>
<td>29.92</td>
<td>0.8</td>
</tr>
<tr>
<td>Attic space</td>
<td>PVC</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thermal performance conditions and energy consumption in base and future scenarios

The Energyplus Software version 8.7 of the US Department of Energy (DOE, 2016) was used to simulate and derive thermal building performance. First, simulation was performed using the current EPW (1961-1990 period), denominated base scenario, and finally using EPW’s generated by the CCWorldWeatherGen tool for the 2020 (2011-2040 period), 2050 scenario (2041-2070 period) and 2080 (2071-2100 period) future scenarios. The low-income house (LIH) Heating Degree-Hours (HDH) and Cooling Degree-Hours (CDH) were used as thermal performance indicator. Base temperature for calculating heating and cooling degree-hours were set to 22°C and 26°C, respectively, and the building was considered to operate naturally ventilated, without thermal load due to occupation, equipment and lighting, following the prescription of the Brazilian Technical Quality Regulation for Energy Efficiency Level of Residential Buildings (RTQ-R) (INMETRO, 2012).

To estimate energy consumption, the LIH simulation was performed considering the artificial air conditioning system (HVAC) operation to provide indoors building habitability conditions. Recommendations prescribed by the RTQ-R (INMETRO, 2012) were used, with the HVAC system operating from 9p.m. to 8a.m. for week and weekend days, and in naturally ventilated condition from 8a.m to 9p.m. Occupation of two people per room, with residential equipment and lighting were considered in this simulation. LIH was considered to have HVAC system Split model with cooling setpoint adjusted to 24°C. The energy consumption for heating was neglected due to the low occurrence of heating degree hours but also because the local population does not use this system in the region. The final energy consuming values were calculated considering the sum of energy spent (in KWh) by equipment, lighting and HVAC in monthly and annual periods.

Strategies of passive mitigation adopted

The mitigation measures adopted considered the passive strategies prescribed by the Brazilian standard NBR 15.575 (ABNT, 2015) and NBR 15.220 (ABNT, 2013a) and in the technical regulation RTQ-R (INMETRO, 2012) for residential buildings inserted in the...
bioclimatic region analysed. The initial envelope thermophysical properties and effective openings areas for windows were compared to the properties suggested by Brazilian regulations, aiming to identify the necessary adjustments to improve building performance and to reduce energy consumption, thus reducing the emissions of greenhouse gases into the atmosphere. Once it is designed to attend Brazilian Technical Regulation and because it aims to become more efficient, the modified house was named RTQ-R efficient LIH. Moreover, such envelope modifications were thought to be capable of being implemented in an easy way in existing buildings, since there are many LIH in use in the region analysed.

Thus, the following modifications proposed were tested: thickness increase of ceramic blocks external mortar (from 0.015m to 0.025m) and changing the external walls painting to white (absorptance from 0.3 to 0.15). For roof, it was proposed to add an aluminium foil for thermal insulation (elevating air thermal resistance in the attic to 0.61m²K/W), to replace the PVC ceiling to thick wooden ceiling (0.01m), and painting the external upper side of tiles to white (absorptance from 0.8 to 0.15) (Table 2). These LIH building modifications adopted are meant to be passive design strategies of thermal inertia, insulation and low absorptance.

Table 2. Modified thermo-physical properties adopted for the housing envelope (RTQ-R efficient LIH).

<table>
<thead>
<tr>
<th>Envelope</th>
<th>Materials</th>
<th>Thickness (m)</th>
<th>Thermal Resistance (m²K/W)</th>
<th>Thermal Transmittance (W/m²K)</th>
<th>Thermal capacity (J/m²K)</th>
<th>Absorp (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>White painting</td>
<td></td>
<td>0.42</td>
<td>2.35</td>
<td>159.66</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Mortar</td>
<td>0.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ceramic brick</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mortar</td>
<td>0.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>White painting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>White painting</td>
<td></td>
<td>1.06</td>
<td>0.94</td>
<td>32.20</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Ceramic tiles</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aluminium foil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attic space</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wooden ceiling</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results and discussion

In the climatic data, it was verified that the average external air temperatures in the 2020s, 2050s and 2080s showed a tendency to increase during all months of the year between 1961 and 2100 (Figure 2). The average annual temperature of the first period (1961-1990) was 26.6°C and it increased to 32.5°C in the period 2071-2100. Therefore, the annual mean dry bulb temperature will increase by 5.9°C between 1961-1990 and 2080s. Similar prospection were inferred by Invidiata and Ghisi (2016), Radhi (2009) and Song and Ye (2017) in other regions of the world.
It is possible to notice that air temperature amplitude for the period 2071-2100 is superior to two previous time slices (2011-2040 and 2041-2070 periods). The same behaviour was predicted in the prospective analysis conducted by Invidiata and Ghisi (2016) in a different climate, which suggests that the impact caused by climate change in this specific period may become a pattern in some regions around the world.

On the other hand, relative humidity tends to decrease during all months of the year between the periods 1961 and 2100 (Figure 3). Annual mean relative humidity will decrease from 69.10% to 53.70% between 1961-1990 and 2071-2100 periods, corroborating with the air temperature pattern described previously.

It is possible to observe that provisions established by the IPCC will affect the degree-hours of the building analysed. The cooling degree-hours will increase by 37,891 hours between the 1961-1990 and 2080 time-slices (Figure 4). Opposite behaviour is observed for heating degree-hours, since climate change will cause its reduction, by 524 hours from the base scenario to the 2080s. In percentages, the cooling demand will increase by 38% in 2020s, 68% in 2050s and 114% in 2080s (Figure 4), corroborating with the elevation of the air temperature observed in the Figure 2. The heating demand, otherwise, will decrease by 46% in 2020s, 64% in 2050s and 85% in 2080s also taking into consideration the baseline.
The LIH redesigned to attend Brazilian Technical Regulation, provides better isolation to the building, reducing the cooling degree-hours of the base scenario (1961-1990) in 11,180 hours, which means reducing 33.7% in relation to the Standard LIH, and in view of climate change, it decreased 25.75% in 2080s. It can be noted that in the RTQ-R efficient LIH, cooling degree-hours will be less affected than the Standard one, but it will still be elevated. It indicates that, despite being more efficient than the first one, strategies adopted to attend Brazilian Energy Efficiency Regulations are not adequate to make LIH resilient to climate change.

![Figure 4. Cooling and Heating degree-hours of the Standard and RTQ-R Efficient LIH.](image)

Following the Cooling and Heating degree-hours (CHDH) behaviour, energy consumption will increase in both buildings analysed (Figure 5). The annual energy consumption of the standard LIH in the base scenario is 3,829KWh/m², rising to 4,581KWh/m² in 2020s, 4,983KWh/m² in 2050s and 5,498KWh/m² in 2080s. It represents increases of 19.6% in 2020s, 30.1% in 2050s and 43.6% in 2080s. These results corroborate with Casagrande and Alvarez (2013) as well as Triana, Sassi and Lamberts (2016) that investigated climate change in other Brazilian cities. Thus, to maintain adequate indoors thermal habitability in 2080s, it will be necessary to provide almost 50% more energy than the base scenario.

The higher isolation provided by the RTQ-R Efficient LIH showed a decrease of 299KWh in 1961-1990, 472KWh in 2020s, 491KWh in 2050s and 476KWh in 2080s totalling an average decrease in energy consumption of 10%, in each time slice, when compared to the standard LIH (figure 5). Thus, despite being more efficient, it is still necessary to adopt more adequate constructive passive strategies in order to meet adequate building thermal insulation that will be resilient to future climate change.
Lastly, it can be observed that the increase in mean air temperature and the decrease in relative humidity directly affect thermal and energy behaviour of the building, affecting its habitability. These increases due to climate change will significantly rise cooling degree-hours and, consequently, rise energy consumption for cooling.

**Conclusion**

When analysing the impact of climate change on a low-income house in the city of Cuiabá-MT, located in the tropical climate of Savannah, it was possible to observe the trend of increasing the annual mean dry-bulb temperature up to 5.9°C in 2080s.

Faced with this reality, it was identified that the building under study is not suitable for habitability on the climate of the region. Including climate change projections established until 2080s, the amount of cooling degree hours will increase 114%. Consequently, the building will require a greater amount of energy consumption to maintain the cooling necessity, and the energy consumption will increase 43.6% from the baseline period to the 2080s.

Therefore, mitigation strategies that could be implemented in existent buildings were sought in order to improve thermal performance and reduce buildings energy consumption. The changes were related to materials of the envelope, taking into account the Brazilian regulations that prescribe passive strategies for each climate of the country, providing passive design strategies of thermal inertia, insulation and low absorptance.

As a result, the building with passive design strategies decreased its Cooling Degree-hours by 33.7% in 1961-1990, and in view of climate change, it decreased 25.75% in 2080s. As for energy demand, it resulted in a total average of 10% less energy consumption than the standard LIH between the 1961-1990 and 2080 periods.

It was noted that rising air temperature and relative humidity decrease directly affect the thermal and energy performances of a building, and these changes, resulting from global warming and climate change, will significantly increase cooling degree-hours, raising the building cooling demand.

Irrefutably, it is evidenced the need to adopt passive project strategies for housing in this climatic zone. For new buildings, it is concluded that there is a need for design strategies to make them resilient to the impacts of climate change. If this is not considered in future projects, the thermal performance of buildings within the tropical savannah climate may increasingly rely on active strategies to provide adequate building habitability, and retrofitting will be more difficult to reverse the thermal and energy inefficiency of buildings.
References


Title: Environmental benefits of using cross-laminated timber with hempcrete insulation in buildings

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Abstract: The build environment, one of the largest energy consumers, is also responsible for around 40% of CO2 emissions in Europe. Under the threat of climate change, legislators and policy-makers keep amending building-related regulations and standards to diminish the building industry's impact on the environment. Along with this trend architectural practices, one of the main generators of innovation in the built environment, have been shifting towards more sustainable designs and use of materials in construction. Part of this endeavour is represented by the recently increased use of cross-laminated timber (CLT) in high-rise buildings and the expansion of hempcrete use. Both of these materials are becoming increasingly popular due to the benefits they offer to a sustainable building economy due to their specific characteristics. Both CLT, made out of cross bonded hardwood panels, and hempcrete, a dried mixture of lime and woody fibres extracted from hemp, have very low embodied energy and also locked CO2 during their growth. Hempcrete has also excellent thermal properties. However, so far they have been considered separately in construction. Thus this paper investigates the environmental benefits of using them together, pondering the pros and cons of doing so. Specifically, it explores the performance CLT and hempcrete together can achieve with a construction technique using a panel of CLT with hempcrete as insulation. The research method used is material exploration and computer modelling with the use of dynamic energy simulation.

Keywords: cross-laminated timber, hempcrete, energy efficiency, overheating, building performance analysis

Introduction

Renewable materials present the environmental benefit of not using resources that may deplete. In particular rapidly renewable materials are those that grow quickly, presenting the benefit of using a modest amount of land for the production of material compared to products that grow slowly. In addition, plants based materials such as timber or hemp generally have a small or even negative CO2 emission during their overall production, as they absorb CO2 during their growth. Hemp in particular is often considered to have low environmental impacts, as the product grows quickly, in a wide range of climates, and without the need of using pesticides or fertilisers. Yet conventional construction materials such as concrete and steel are preferred as they have excellent performance in terms of cost, structural integrity and fire resistance rating (Crawford et al., 2017). Unfortunately the use of such materials results in large climate change impacts from extraction, transformation during and even after construction. Although there has been an increased improvement in the production phase to decrease the environmental footprint of such materials, the construction industry still utilises raw materials that are not renewable resulting in resource depletion. Yet, there is an increased awareness of the importance of renewable materials in the construction industry. Mass timber construction has seen a steep increase since 2003. During that year there was only one manufacturer of CLT in Europe, in 2007 there were 50 globally, signalling an increase in demand and awareness (Crawford et al., 2017). During the construction stage the use of timber has been evaluated to reduce embodied greenhouse emissions as well as transportation emissions (Sandanayake et al., 2018), compared to concrete, making it a suitable material for future construction methods. When compared with conventional prefabricated
timber modules and laminated veneer lumber across energy efficient levels, CLT was proven to have the lowest lifecycle carbon emissions (Dodoo et al., 2014). However, it has been argued that in some cases concrete presents the benefit of reducing cooling loads compared to CLT hence reducing energy use in the long run.

This paper is an exploratory research that investigates three types of CLT and hempcrete panels against a CLT and wood fibre insulation base case and against each other. Their composition is with the hempcrete insulation to the exterior, to the interior and to both interior and exterior of a CLT wall. Through energy simulation realised with the IES software, the monthly, yearly energy and peak power levels on one hand, and the overheating risk on the other hand were compared. The results showed insignificant differences in the outcomes in all the situations, indicating the need of a further and deeper investigation, including experimentation.

Overview

CLT and hempcrete represent the construction elements investigated within this paper. This section is an overview of the main characteristics of the CLT and hempcrete. CLT is constructed from cross sections of timber glued together perpendicularly to each other. The accepted thicknesses of timber lamellae in Central Europe are 20mm, 30mm, 40mm. The overall dimensions of timber panels achieved are 3.8m width and 30m length, although, typically are constructed up to 3m long and 18m long for efficient transportation. In Europe, the use of Norway spruce wood species is typical for softwood species however hardwood has also been used for CLT panels. Different species have been used internationally depending on the climate and wood availability or suitability (Brandner et al., 2016). Softwood timbers typically used are larch, white fir, silver fir, Douglas fir and pine. (Sutton et al., 2011). CLT is an excellent structural material, and even an effective system for seismic areas (Ceccotti, 2013).

Hempcrete is “a non-structural composite material obtained from a mixture of hemp shives […] and a lime based binder” (Arrigoni et al., 2016). The hemp product used in hempcrete is actually the inner woody stern (the ‘shiv’, ‘shive’ or ‘hurds’) of the Cannabis ruderalis variety of hemp, which contains very little tetrahydrocannabinol (THC), the psychoactive substance (Stanwix et al., 2014). The lime-based binder contains 75% hydrated lime (98% CaO), 15% of hydraulic binder and 10% of pozzolanic binder (Pretot et al., 2014). Hempcrete bricks have very good insulation, acoustic and psychrometric properties, are resistant to fire, to frost, to insects and to rodents (Arrigoni et al., 2016). In terms of durability, research has not been conclusive, but the properties of lime in the mixture have proved to enhance the “mechanical performances of the wall exposed to air”. (Arrigoni et al., 2016). During the operational phase, the hempcrete mixture continues to absorb and store for the rest of its life carbon dioxide from the atmosphere in a process called carbonatation (Arrigoni et al., 2016), this increasing the wall’s prerogative as a carbon sequestration component of the building and contributing to its sustainable characteristics. Research has shown that in a 25cm thickness brick wall with both sides exposed to air, in the first 150 days, 1.7 kg of CO₂ can be already absorbed by a squared meter of hempcrete wall, this representing approximately 9% of the total amount of CO₂ that the wall could absorb (Arrigoni et al., 2016). According to Ip et al., (2012), the carbon sequestration capability of one square metre of wall is of 82.71Kg CO₂eq. Another benefit of the hempcrete bricks is that they can be reused at the end life of the building, thus reducing environmental impacts.

Thermal and hygrothermal properties

Hygrothermal performance

Several studies identify a lack of adequate knowledge in relation to the vulnerability of timber to moisture (Brandner et al., 2016; Lepage, 2017). A study in Ontario, US, undertaken by McClung...
(2013), which tested different wood species for the moisture content over one year, concluded that the drying behaviour of wetted CLT was not affected by the wood species rather by the configuration of the wall assemblies, this permitting the use in construction of a wide variety of wood species with similar outcomes in terms of moisture. A separate study performed in Vancouver by Lepage (2017), on CLT floors identifies the issue of high moisture content during construction. The study suggests the use of non-porous vapour impermeable coating applied on dry CLT during manufacturing could eliminate the risk of biodeterioration. According to Arrigoni et al. (2016), hempcrete brick has good moisture buffering capacity. The average moisture buffer value of precast hempcrete is 1.94 (Collet et al., 2013). Pretot (2014) stated that “Its hygrothermal behaviour reduces energy needs while maintaining high indoor comfort”.

**Thermal mass**

Thermal mass is the capacity of a material to store heat from the surrounding air or surfaces (Pelsmakers, 2015), in a building this working as a regulator of temperatures between day and night. The denser the materials are, the better their thermal capacity is (Pelsmakers, 2015). The thermal mass of a material can be used to help the effectiveness of passive design, saving energy and promoting milder temperature in a building, if used appropriately. Thermal mass can be used for the purpose of storing heat from solar heat gains during cold weather. However Dodoo et al. (2012), notes that the effectiveness of thermal mass in buildings depends on the interactions of several parameters including climatic location, orientation, window area, insulation, ventilation, load profile and occupancy pattern of buildings.

The factors that influence thermal mass are:

a) specific heat capacity, the capacity of a material to store heat for every kilogram of mass (J/kgK) – the higher the specific heat capacity, the higher the thermal mass

b) density, the mass per unit volume of material (kg/m$^3$) – the higher the density, the higher the thermal mass

c) thermal conductivity, the ease with which heat can travel through a material (W/mK) – moderate thermal conductivity for high thermal mass, to ensure that “the absorption and release of heat synchronises with the building’s heating and cooling cycle” (Greenspec, no date).

CLT is considered a lightweight structural material and has lower thermal mass than heavyweight structural materials such as brick or aircrete (Sutton et al., 2011). A study monitored two prefabricated timber buildings located in the UK, one constructed from cross-laminated timber and the other from structural insulated panels. The result of the study was that higher floors with southern orientation experienced warmer conditions and the design of the floor to ceiling height ration contributing to summer overheating (Adekunle and Nikolopoulou, 2016).

Hempcrete is often considered to have a good thermal mass, due to its high specific heat (de Brujin et al., 2013), and consequently is able to store high amount of heat. This potentially could present benefits in terms of preventing overheating in buildings and moderating temperature variations. Hempcrete consequently appears as a good candidate as a companion to CLT, adding the insulation and thermal properties required to improve internal comfort.

**Energy consumption and overheating**

The evaluation of the benefits of using a composite panel of CLT and hempcrete involves the assessment of the energy consumption and overheating risk whilst using this construction element.

According to the definition of TM 56 (BRE, 2016), overheating takes place when the building occupants feel “uncomfortably hot” at a certain moment or over a longer period, due to the indoor environment, when the temperature in the building is too high for comfort. TM 59 (CIBSE, 2017) provides the methodology for assessing the overheating risk and the compliance is ensured through the following criteria:
a) hours of exceedance: when for living spaces the “number of hours during which ΔT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 per cent of occupied hours”;
b) for bedrooms only, when the “operative temperature in the bedroom from 10pm to 7am shall not exceed 26°C for more than 1% of annual hours”.

**Prefabricated CLT – hempcrete panel proposed**

**System proposed**

The study aims to review the performance of a wall composed of CLT as a structural element, and hempcrete as its insulation and thermal mass. Beyond its environmental benefits, CLT presents the sizable advantage of offering a rapid method of construction on site. Unfortunately, hempcrete can take a substantial amount of time to cure, and consequently it is suggested that the hempcrete could be cured off site, and that panels of prefabricated hempcrete are made to match CLT panels. The CLT and hempcrete would form together prefabricated panels (Figures 1-3) that can be used in the construction of buildings. The performance of the hempcrete-CLT panels will be compared amongst themselves as per the scenarios described below and against a base case of a current construction type. Based on the location of the hempcrete insulation panel, three types of panels will be tested, from this point onwards named Panel (a), Panel (b), Panel (c):

- **Panel (a)** – 300mm hempcrete panel placed on the external face of a 120mm CLT panel (Figure 1);
- **Panel (b)** – 300mm hempcrete panel placed on the internal face of a 120mm CLT panel (Figure 2);
- **Panel (c)** – 150mm hempcrete panel placed on the internal face and 150mm hempcrete insulation panel placed on the external face of a 120mm CLT panel (Figure 3).

**Properties of the materials**

**Hempcrete composition**

It consists of: density: 330kg/m³ (UK Hempcrete, 2015); thermal conductivity: 0.07W/mK; the lime binder and hemp shiv ratio is 1 to 3 as per Arrigoni et al. (2016); specific heat capacity: 1600 J/kg*K.

**CLT composition**

As a natural renewable product performance can vary slightly, but commercial cross-laminated timber systems generally achieve (Sutton et al., 2011): thermal conductivity: 0.13 W/mK, density: 480–500 kg/m³ (spruce) and specific heat capacity: 1500 J/kg*K.

**CLT and hempcrete panel types**

The structure of the external wall for the three scenarios investigated is as shown in Table 1. In any of the scenarios, the structure does not contain plasterboard and service void to the interior in
order not to create a barrier to the thermal mass of the material. The risk of condensation was examined for each of the CLT-hempcrete construction scenarios and it showed no risk of condensation for panel (a), a slight risk for panel (c) and a more significant risk for panel (b).

| Table 1. Structure of the external wall for Panels (a), (b) and (c) |
|-------------------|-------------------|-------------------|
| **Panel (a)**     | **Panel (b)**     | **Panel (c)**     |
| **Materials**     | **Thickness (m)** | **Materials**     | **Thickness (m)** | **Materials**     | **Thickness (m)** |
| CLT               | 0.120             | Hempcrete         | 0.300             | Hempcrete         | 0.300             |
| Hempcrete         | 0.300             | CLT               | 0.300             | Hempcrete         | 0.120             |
| Breather membrane | 0.0002            | Breather membrane | 0.0002            | Hempcrete         | 0.150             |
| Cavity (with timber studs) | 0.040 | Cavity (with timber studs) | 0.040 | Breather membrane | 0.0002 |
| Timber cladding   | 0.020             | Timber cladding   | 0.020             | Cavity (with timber studs) | 0.040 |
|                   |                   |                   |                   | Timber cladding   | 0.020             |

Methodology for the thermal analysis

This analysis aims to understand whether the use of CLT and hempcrete panel walls would bring any energy saving and overheating risk benefits compared to a traditional building model. The research uses IES-VE software for computer simulation to investigate the environmental impact and overheating risk of CLT-hempcrete panel structures in comparison with a traditional construction structure. Although the study from Pretot et al. (2014), showed that in the case of hempcrete “the production of raw materials is the most impacting phase” to the environment (essentially due to binder production), and other studies have aligned to the same idea of considering hempcrete throughout its all life length (Arrigoni et al., 2016), this study will take into consideration only the operational stage, which has proved to have the highest impact, with around 80-90% of environmental impacts, as opposed to 10-20% as per the embedded impacts (Ramesh et al., 2010). The studs were not considered thermal bridge as they were an addition to the structure assessed, with thermal conductivity similar to that of CLT (Pretot et al., 2014).

The description of the case study house

The case study is Bedroom 2 in a three-storey mid-terrace house (Figure 4) in East London, facing south-west at an angle of 21° from north. The occupancy profile used is an outside office hours for full-time employees with 09:00-17:00 working hours. There is no living-room, and therefore the most of the time is spent in the bedroom. Thus, the occupied hours cannot be limited to only 22:00-07:00, as in other studies (Porritt et al., 2011) and TM59 (CIBSE, 2017).
Parameters and assumptions

The period of time to be investigated is 1 October–30 April for the winter period (CIBSE, 2016) for energy consumption purposes, and 1 May-30 September for summer time for overheating risk assessment (CIBSE, 2017). Similarly to other researches (Gupta et al., 2012), the weather files used are the Prometheus files at the Islington meteorological station, based on UKCP09. For energy assessment the files used are the TRY (Test Reference Year) 1970s file (based on the 1961-1990 period), as recommended by CIBSE (2016), as a control file and 2050 high emissions 50% percentiles as a future weather file. For assessing overheating risk the DSY (Design Summer Year) files are used similarly (CIBSE, 2017). The research data employed was primary data from the inputs of the building’s characteristics, and secondary data from major manufacturers and previous research. The other IES room conditions are described in Table 2.

Table 2. IES room conditions

<table>
<thead>
<tr>
<th>Energy consumption</th>
<th>Overheating risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>off continuously</td>
</tr>
<tr>
<td>Cooling</td>
<td>off continuously</td>
</tr>
<tr>
<td>Windows opening</td>
<td>off continuously</td>
</tr>
<tr>
<td>Air infiltration rate</td>
<td>0.250 ach</td>
</tr>
<tr>
<td>Air speed</td>
<td>0.15m/s</td>
</tr>
<tr>
<td>Internal gains</td>
<td>fluorescent lighting and people</td>
</tr>
<tr>
<td>Activity level (TM52)</td>
<td>90</td>
</tr>
<tr>
<td>Clothing level (TM52)</td>
<td>0.69</td>
</tr>
<tr>
<td>Building category</td>
<td>Category II (new builds and major refurbishments)</td>
</tr>
</tbody>
</table>

Although Building Regulations Part L imposes the design to acknowledge and take into account thermal bridges (HM Government, 2013), as the scenarios investigated for the south-west facing wall involve the use of pre-fabricated CLT-hempcrete panels, thermal bridge is assumed insignificant and therefore not considered in this research. For all the construction systems tested, the U-value was the same and in compliance with the Building Regulations Part L.

The base case study building and scenarios description

Based on the previous considerations, this paper looks into a comparison for energy consumption and overheating risk between the three panels proposed and against a base case, to identify the most appropriate outcome. For the purpose of this paper the structural composition of the walls of the current house has been changed to meet the requirements of the base case and investigated panels. Thus, the base case structure of the house is of 120mm CLT, with wood fibre insulation, replaced with hempcrete insulation for the other scenarios. The composition of the external walls, including external windows, for all these cases is detailed in Tables 3–7. The base case study used as referential for all the CLT-hempcrete panel-based investigations is composed of CLT and wood fibre insulation with the structure represented in Table 3.
Table 3 Structure and characteristics of the external wall of the base case

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Conductivity (W/m K)</th>
<th>Density (Kg/m³)</th>
<th>Resistance (m²K/W)</th>
<th>Vap resist. (GNs/kg m)</th>
<th>U-val. (W/m²K)</th>
<th>Total thickness (mm)</th>
<th>Therm mass (KJ/m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>Timber cladding</td>
<td>20</td>
<td>0.13</td>
<td>500</td>
<td>0.154</td>
<td>4</td>
<td></td>
<td>0.175</td>
<td>380</td>
</tr>
<tr>
<td></td>
<td>Cavity</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>0.180</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breather membrane</td>
<td>0.02</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood fibre insulation</td>
<td>180</td>
<td>0.07</td>
<td>330</td>
<td>4.29</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CLT</td>
<td>120</td>
<td>0.13</td>
<td>500</td>
<td>0.692</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The composition of the external windows used in the house was the same in all the scenarios investigated. Their structure is shown in Table 4.

Table 4. Current house specifications for external windows double-glazing (IES software)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Conductiv. (W/m K)</th>
<th>Gas</th>
<th>Resistance (m²K/W)</th>
<th>Net U-value (+ frame) (W/m² K)</th>
<th>U-value (glass only) (W/m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Pane</td>
<td>4.00</td>
<td>1.30</td>
<td>2.00</td>
<td>1.06</td>
<td>Argon</td>
<td>0.00</td>
<td>1.44</td>
<td>1.09</td>
</tr>
<tr>
<td>Cavity</td>
<td>16.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner Pane</td>
<td>4.00</td>
<td>-</td>
<td>-</td>
<td>1.06</td>
<td>-</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scenarios investigated

The scenarios investigated refer to the replacement of the south-west facing base case external wall of Bedroom 2 with the CLT-hempcrete panels defined in the previous sections. The characteristics of the walls resulted are as per Tables 7-9 below.

Table 5 Structure and characteristics of the external wall when using Panel (a)

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Conductivity (W/m K)</th>
<th>Density (Kg/m³)</th>
<th>Resistance (m²K/W)</th>
<th>Vap resist. (GNs/kg m)</th>
<th>U-val. (W/m²K)</th>
<th>Total thickness (mm)</th>
<th>Therm mass (KJ/m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>Timber cladding</td>
<td>20</td>
<td>0.13</td>
<td>500</td>
<td>0.15</td>
<td>200</td>
<td></td>
<td>0.175</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Cavity</td>
<td>60</td>
<td>-</td>
<td>-</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breather membrane</td>
<td>0.02</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hempcrete</td>
<td>300</td>
<td>0.07</td>
<td>330</td>
<td>4.29</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CLT</td>
<td>120</td>
<td>0.13</td>
<td>500</td>
<td>0.92</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 Structure and characteristics of the external wall when using Panel (b)

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Conductivity (W/m K)</th>
<th>Density (Kg/m³)</th>
<th>Resistance (m²K/W)</th>
<th>Vap resist. (GNs/kg m)</th>
<th>U-val. (W/m²K)</th>
<th>Total thickness (mm)</th>
<th>Therm mass (KJ/m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>Timber cladding</td>
<td>20</td>
<td>0.13</td>
<td>500</td>
<td>0.15</td>
<td>200</td>
<td></td>
<td>0.175</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Cavity</td>
<td>60</td>
<td>-</td>
<td>-</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breather membrane</td>
<td>0.02</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hempcrete</td>
<td>300</td>
<td>0.07</td>
<td>330</td>
<td>4.29</td>
<td>10</td>
<td></td>
<td></td>
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</table>

Table 7 Structure and characteristics of the external wall when using Panel (c)

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Conductivity (W/m K)</th>
<th>Density (Kg/m³)</th>
<th>Resistance (m²K/W)</th>
<th>Vap resist. (GNs/kg m)</th>
<th>U-val. (W/m²K)</th>
<th>Total thickness (mm)</th>
<th>Therm mass (KJ/m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>Timber cladding</td>
<td>20</td>
<td>0.13</td>
<td>500</td>
<td>0.15</td>
<td>200</td>
<td></td>
<td>0.175</td>
<td>500</td>
</tr>
</tbody>
</table>
The rooms surrounding the bedroom investigated are considered to have a similar temperature to the room investigated, so that their temperatures would not influence the outcomes of the energy consumption and overheating risk of the investigated room. As the hempcrete remains exposed to interior of the room in scenarios Panel (b) and Panel (c), a layer of coating with no influence to thermal mass properties of the hempcrete is assumed.

**Results**

**Overheating**

The results refer to TM 59 criteria (CIBSE, 2017) as mentioned above. They showed insignificant variations in the percentage of hours above 26°C between the three panels investigated, and similarly between these and the base case. This applies to both 24-hour occupancy profile and the set occupancy profile. These outcomes resulted from both current and 2050 weather file use. In terms of overheating risk all panels and the base case resulted in none or almost no risk for the current weather file, but more significant for the 2050 future files (Figures 5 and 6).

![Figure 5. Percentage of hours when the operative temperature in Bedroom 2 is above 26°C for the current weather](image)

![Figure 6. Percentage of hours when the operative temperature in Bedroom 2 is above 26°C for the 2050 high emissions 50% percentile weather](image)
**Energy**

Similarly to the outcomes of the overheating risk analysis, the main results of the energy simulation show insignificant differences in the performance of the three panels and the case study. Thus, regarding the monthly energy levels, there are different fluctuations between the three panel types, the weight of the values varying amongst them, but not significantly for both current and future weather files (Figures 7 and 8).

![Figure 7. Monthly levels of energy of the three panels and case study for the current weather](image)

![Figure 8. Monthly levels of energy of the three panels and case study for the 2050 high emissions 50% percentiles weather](image)

In terms of yearly energy levels, Figure 9 for current weather and Figure 10 for 2050 weather scenarios show the same insignificance difference between the results. All three panels perform slightly better than the case study, and panel (a) has the lowest energy consumption, whilst panel (b) recorded the highest energy levels of energy consumption, making it the least energy efficient panel system, although the minor differences recorded render them all as insignificant outcomes.
The peak power levels (Figures 11 and 12) show the same degree of insignificance between the results. Amongst them them, panel (a) has the lowest value of 4.94kW, with panels (b) and (c) performing almost similarly but higher, the base case having the highest value of 5.02kW.
For a better representation of the outcomes, these results need to be taken into consideration in association with the levels of thermal mass resulted from the structure of the construction element (as per Tables 3, 5, 6, 7), topic which could be discussed in a further and more detailed research.

Conclusions

A prefabricated panel of CLT together with hempcrete would present the combined benefits of being an efficient construction system with extremely minimal environmental impacts. This research aimed at investigating whether such a product, and different variations of its composition, would present benefits in terms of energy saving and overheating risk. This research shows that in the case study of a bedroom presented, there is no clear benefit from the point of view of energy and overheating in using one panel system over another, as the results are very close to one another. Yet this result may not be valid for all situations, building types, orientations and locations. We suggest that further investigations, extended to a wider range of case studies could be useful to establish where such benefits may be more important. In addition, experimentation could also be carried out in order to test the modelling results.

References


A Study on the Application of Thermal Insulation Techniques under a Mild Mediterranean Climate

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Abstract: The construction sector is currently responsible for a large portion of the total energy use worldwide. In many countries, efforts are being made to reduce energy consumption through improvements of overall energy efficiency in buildings. However, a majority of the standing constructed facilities in Lebanon are lacking in terms of design and material considerations and as such pertain low energy efficiency, increased risk of mold condensation, and general tenant discomfort. As such, this paper focuses on the performance of different thermal insulation techniques in mild Mediterranean climates and their effect on building energy consumption and indoor thermal comfort. More specifically, the study analyzes the heat exchange through the surfaces and thermal bridges of the two most adopted construction types of mid-budget residential buildings in Lebanon. The objective is thereby four-fold: (1) Identify existing thermal “weak points” in construction by means of a thermal imaging camera, a nondestructive tool gaining momentum in the civil engineering research field, (2) Simulate, in 2D and 3D, different scenarios for insulation positions and structural thermal breaks in order to assess the thermal performance in winter and summer climatic conditions, (3) Study and integrate human comfort levels and the mitigation of health implications, and (4) Assess the economic feasibility of implementing the decided combination of optimum solutions. Experiments were conducted and results showed significant reductions in building energy consumption in general, and promised decreased likelihood of mold condensation, the extent of which depends on the architectural plans.

Keywords: Thermal imaging, thermal bridges, thermal comfort

Introduction and Background

With the upsurge of energy demand for the provision of lighting, heating and cooling of buildings, environmental issues have begun posing a greater threat to the planet as a whole. An increase in a building’s energy expenditure can be interpreted as both higher operating costs and a larger carbon footprint. Carbon dioxide is a harmful pollutant that underlies many health hazards for people and plays an important role in contributing to the greenhouse gas effect. If left unmanaged, a rise in temperatures by as much as 4°C is expected by the end of the 21st century (Almazroui et al, 2017). This would have drastic consequences on global agriculture, ecosystems, climates, and sea water levels (Hansen et al, 2015). While passive measures can be taken to reduce the primary energy consumption (Synnefa et al, 2017), proper material selection and implementation during the construction phase can greatly influence the operational energy demand of a building (Theodosiou et al, 2008).

Therefore, this study focuses, in particular, on setting guidelines for effective insulation strategies in buildings under a mild Mediterranean climate. Since the energy consumption in buildings is subject to the effects of heat exchange through the building envelope, reducing the heat transmission through walls retains great importance in energy conservation (Ibrahim, 2011). In fact, thermal insulation in buildings is a simple yet highly efficient way to reduce the heat transfer rate and energy use for internal temperature
regulation. This can be attributed to the large thermal resistance values of the implemented composite materials that are preventing heat flux with the surrounding environment (Li et al, 2016). In addition, minimizing the heat exchange through thermal bridges could also be a solution for the aforementioned problem (Ge et al, 2013). As a matter of fact, thermal bridges, which are important joints in the building envelope, are responsible for a major reduction in the interior surface temperature of walls and corners (Asdrubali et al, 2012); otherwise, there would be a risk of mould accumulation and condensation in winter. Construction errors further reduce the thermal efficiency of those joints (Alencastro et al, 2018). As such, an account of the various thermal characteristics of the materials used in construction must be determined to achieve a better building energy performance. These include the thermal transmittance (“U-value”) of surfaces, which helps determine the building’s energy demand, the linear thermal transmittance of joints (“Psi-value”), and the temperature indices (“fRsi”) (Gaspar et al, 2016).

Heat loss in buildings can occur through both the wall surfaces of the envelope as well as lines of structural element intersections, or the thermal bridges. These lines induce various effects on the building’s performance including a higher heat transfer rate through the assembly, or a greater heat loss, colder surface temperatures on the warm side of the assembly, and warmer surface temperatures on the cold side of the assembly. This heat loss consequently results in a lower fRsi value which indicates greater energy use, dampness and water condensation, mould growth, and the corrosion of metal elements and structures (Schöck Isokorb, 2014). More specifically, mould growth at thermal bridges is a serious issue originating from uneven moisture levels (Goldstein, 2011) that can cause “moisture cracking” and pose immense risks on a building’s stability and resilience (Ettouney et al, 2016). Studies have shown that five to ten percent of cold climate households and ten to thirty percent of moderate and warm climate households include mould (Jaakkola et al, 2011) (WHO, 2011). This exposure is deleterious to household health and can cause coughing, wheezing, upper respiratory tract problems, asthma exacerbation, and hypersensitivity pneumonitis (Quansah et al, 2012). It has been shown that the avoidance of mould condensation requires an fRsi value larger than 0.80 (Kalamees, 2006). As such, these facets of concrete moisture instigate the need for better strategies regarding building infrastructure and concrete dampness. This, in turn, would improve public health and would consequently save a lot of money in healthcare costs.

A proposed solution to the aforementioned problem would be the integration of structural thermal breaks, a design that separates interior and exterior structures and highly reduces heat transmittance and thermal conductivity at joints (Schöck Isokorb, 2014). In fact, previous studies have analysed the difference in the thermal behaviour of insulating reinforced elements and conventional reinforced concrete. The analysis showed that correcting a thermal bridge with insulating reinforced elements could increase the interior surface temperature and reduce the heat exchange between the exterior and interior (Dikarev, 2016). In addition, another research effort was conducted on the effect of thermal bridges for terraced and semi-detached houses in the Italian climate, which is an example of a mild Mediterranean climate similar to Lebanon’s climate. The buildings that were studied are composed of reinforced concrete frameworks and clay block walls. Results concluded that the correction for thermal bridges is effective in reducing energy needs for winter heating season, while only a slight improvement in energy needs was required during the summer cooling season (Evola et al, 2011). Other studies have tackled the effects of architecture on the application and effectiveness of thermal insulation techniques. For
example, a larger house size or a higher number of the household may diminish the effectiveness of insulation (Viggers et al, 2017). In addition, the position of the installed insulation can also highly influence the thermal performance of a building (Wang et al, 2016).

Despite the numerous case studies conducted in mild Mediterranean climates, there is little research available for the Middle Eastern region. As a matter of fact, most of those examinations lack accurate accounts of total insulation effects on mould condensation, thermal comfort levels, and design integration, even with the emerging study techniques on thermal bridges through thermography (Baldinelli et al, 2018). As such, this study makes use of these rising techniques to propose a sample of insulation methods which could result in better thermal performance for the existing residential buildings in Lebanon under lesser operation costs and better occupant comfort levels.

Methodology

The methodology addresses issues in three specific task areas: (1) data collection, (2) 2-D heat transfer simulations, and (3) 3-D room temperature simulations.

Data Collection

This task is performed through conducting a preliminary site visit in order to determine the current construction conditions. These findings include the slab type, external wall thicknesses, building orientation, wind direction, weather data, and notes of any visible construction errors. However, if the building is not in the construction phase yet, the details can be acquired from the structural plans while assuming as-built ones will be accurate. In the case of completed buildings, studies are conducted through the use of a thermal camera in order to determine the location of any thermal leakage in the structure.

2-D Heat Transfer Simulations

To proceed with the study, an accurate account for any heat transfer coefficients should be made. This entails the identification of the U-value of surfaces, Psi-value of linear thermal bridges, and the risk of condensation on surfaces and corners. The various data or sections are pooled into the HTFlux simulation software and material assignments are executed based on the provided structural and architectural details. The simulated components include balconies, walls, windows and doors of the building under discussion.

Once the reference scenarios are set up, solutions to the thermal leakages are integrated and the simulations are run again. The new values of heat transfer coefficients are then compared with the first obtained values to determine the efficiency of the selected solution. It is worth noting that weather details are procured from the nearest weather station, should the conditions match the same ones at the construction site. Otherwise, it is preferable that an onsite study should be conducted.

3D Room Temperature Simulation

In this stage, a sample number of rooms are chosen and simulated in 3-D conditions. The room is imported from a Building Information Modeling (BIM) model into the Computational Fluid Dynamics (CFD) software and its materials are assigned based on the data collection phase.

Film coefficients of the exposed surfaces are assigned as per the results collected from the 2-D heat transfer simulation phase combined along with the available weather data and
the assumed internal temperatures. In addition, the air volume inside is then studied to acquire a general temperature value and any notes on in-room variations are recorded. A human model is added as well to study the expected thermal comfort levels. Subsequently, and to allow for a more accurate outcome and an efficient solution, this setup is repeated twice; once having the default conditions as point of reference, and another using the integrated solutions.

Case Study

In this study, four buildings belonging to different construction eras (1926, 1949, 1973, and 2010) and situated in Lebanon on Makhoul Street in Beirut were selected in order to provide a more diverse material quality. Furthermore, the buildings were chosen taking into consideration they share a common sun exposure level and similar orientations. Accordingly, thermal images were captured in these buildings and thermal bridging was studied and detected by identifying differences in the colour-temperature diagrams of these images.

Next, a residential building under construction was selected as a default scenario onto which the proposed solutions were simulated and analysed. More specifically, the following sections were adopted in the HTFlux simulation studies:

i. Balcony section (default).

ii. Balcony section with a top double-glazed door (air fill).

iii. Slab edge section (default).

The configurations (i) through (iii) represent the as-designed components of the ongoing residential building. Both balcony and slab edge sections were simulated with the addition of a 3 cm Expanded Polystyrene (EPS) insulation layer in different positions (e.g. interior, middle and exterior), and with the exterior double wall built continuously along the face of the building. Additionally, only the balcony sections were simulated with an exterior façade wall and an added structural thermal break as well as with an exterior insulation layer and a structural thermal break. Figure 1 below depicts a sample as-designed section of a balcony, including dimensions as well as specifications for materials and boundary conditions for the case of a simulation during the winter season.

![Figure 1. Materials and Boundary Conditions Used for Winter](image-url)
Results and Analysis

Heat Transfer Simulation Results

Following the 2-D heat transfer simulations run on the default scenario of the ongoing project, the temperature flow diagrams of the studied configurations were determined, along with the thermal performance or U-values of surfaces, the linear thermal transmittance or Ψ-values of thermal bridges, the temperature factor or fRsi-values of surfaces and corners, and the lowest and highest interior surface temperature values. The temperature flow diagrams indicate the location of thermal bridges through the non-parallel isotherms and show that the most important thermal bridges in a building envelope are located at balconies and slab edges. These are also verified by the Ψ-values, indicating a high linear thermal transmittance at those joints. In addition, after conducting a site visit to the building under construction, it was found that these sections are not constructed exactly as the design plans and specifications indicate. As a matter of fact, since the walls are made of concrete hollow blocks with designated set of dimensions, the small depths left between the last concrete block layer of the wall and the reinforced concrete slab are filled with cement paste. This, in turn, dries with time, shrinks and cracks, giving way for higher thermal bridging effects than the ones already identified through 2-D simulations. Consequently, a higher heat flux is witnessed through those joints when the interior would be either heated in winter or cooled in summer.

Below is a sample output of a slab edge section under different construction scenarios. The first considers the typical double wall construction method; the second presents a continuous exterior insulation, while the third presents a section with an exterior façade wall as shown in Figures 2, 3, and 4, respectively.

Figure 2. Slab Edge – Default
As noticed, once a continuous insulation layer is inserted at the exterior side of the wall (Figure 3), there is a major drop in the amount of heat loss at the thermal bridge of the wall-slab connection (lower Psi-value). An even further drop in the amount of heat loss is witnessed when the slab is not directly in contact with the external climate (Figure 4). The minimum temperature in the connection increased by 3.1°C, while the fRsi value also increased from 0.78 to 0.93; thereby eliminating the probability of having mould condensation at the corner of the room.

All simulations were repeated given various winter and summer boundary conditions, and accordingly their respective results were tabulated. The following tables (Tables 1 and 2) show the U, Psi, fRsi and lowest temperature values for winter simulations, in particular, and for two types of construction methods.
As reflected through the U-values obtained from winter simulations (Tables 1 and 2), double walls transmit less heat than single walls, and accordingly are more adequate for the thermal efficiency of the building. Regarding the position of insulation, the results revealed that the external and internal placement of the EPS layer on double walls gives the lowest U-value (Table 1), resulting in less heat loss and greater heat efficiency when the interior of
the building is respectively heated in winter or cooled in summer. In fact, the optimum position of insulation depends on the occupancy. If the insulation is placed on the interior side, heating the room in winter requires a smaller time interval as the generated heat does not penetrate the wall. This configuration could be best applied in the case of office use, where the occupants prefer rapid heating of their workplace and do not require any wall heat retention. However, in the case of the exterior insulation layer (Figure 3), the walls accumulate heat when the room is heated. Hence, when the heat source is turned off, the walls emit the heat accumulated and by that taking a greater amount of time for the room to cool back down. This configuration is best used for residential buildings, where occupants control or keep a time limit on operating the heater throughout the day due to incurred costs. Therefore, in this case, the best insulation position is clarity to be on the exterior face of the walls. As for the external façade wall scenario (Figure 4), the thermal transmittance (i.e. U-values) of the wall is larger than that of the exterior insulation case, yet less than the default value in case of double walls (Table 1). Nevertheless, it was shown through the simulations that the linear thermal transmittance (i.e. Psi-values) decreases drastically on the slab edge when this solution is implemented as reflected through the Section (iii) results in Table 1. Furthermore, the results of the double wall simulations with the structural thermal break implemented over either the external insulation or an external façade wall showed Psi-values that favour the application of thermal break with exterior insulation rather than the integration with an external façade wall (Table 1). As such, and in the case of an existing double wall construction, the most efficient solution for minimizing heat exchange would be using double walls with external insulation along with the structural thermal breaks.

However, when the simulations were repeated for the same building assuming a single wall and normal slab, an external façade wall proved to provide a better insulation method with greater heat retention values (Table 2). As for the temperature factor (i.e. fRsi) calculations, the simulation values obtained at the critical locations of the default sections were generally less than 0.80 under winter conditions. This indicates that there is a high chance of mould accumulation in these relative sections’ corners given the temperature, humidity and resistivity boundary conditions. The fRsi values increase during winter when the external insulation or the external façade wall is implemented along with a structural thermal break (Table 2), which further indicates the importance of these solutions for maximizing the building energy efficiency and the occupant overall comfort.

On the other hand, the summer simulation results generated the same U-values and Psi-values as the ones obtained for the winter season. However, a difference was noticed in the fRsi-values, and also in the minimum and maximum temperatures at the interior surfaces. More specifically, the generated fRsi values are actually larger than 0.99, thereby indicating a non-accumulation of mould on neither the interior surfaces nor the corners throughout the cooling season. In addition, these results coincide with the literature review, indicating that the thermal breaks do not have a significant impact on the improvement of the indoor air temperature.
**Room Temperature Simulation Results**

This section presents the room temperature simulation results for the heating season in winter. More specifically, Figure 5 visually depicts results for an average single wall construction versus those for a design with the implemented exterior wall façade (i.e. proposed solution).

![Figure 5: Thermal Result of the Single Wall Design (left) vs. the Design with an External Facade Wall (right)](image)

It can be noted from the colour patterns in Figure 5 (right) that the room where the external façade wall is installed is considerably warmer than its as-designed counterpart (Figure 5, left). These visual results were further verified through the generated heat exchange report whereby the average air volume temperatures increased about 3 to 4°C after installing a continuous external façade wall and the minimum room temperature, located at the base of the external wall, rose by around 5°C.

Furthermore, the occupant thermal comfort level can be assessed through a predicted mean vote (PMV) value. This value varies between -3 and 0 with the former being an indication of discomfort due to cold, and the later a discomfort due to heat. In this scenario, the mentioned temperature increased by 4°C corresponding to a 0.5 PMV shift from -3 to -2.5. It is important to note that this shift was achieved without the use of any heating devices and is completely attributed to the implemented solutions.

**Energy and Cost Savings Calculation**

This section aims at quantifying the energy savings and related benefits and costs generated from implementing the suggested solutions. This is achieved by calculating the amount of energy dissipated from the walls and bridges for each scenario then defining the energy saved as the difference between the as-designed plans and the integrated solutions.

Accordingly, using the following formula, results were generated and are shown in Tables 3 and 4.

\[
\text{Seasonal Heat Loss} = \frac{\text{Area Elements}}{R - \text{Value}} \times 24 \times \text{HDD}
\]

Where:
- HDD is the number of Heating Degree Days
- R-Value is the thermal resistivity value of the element
Table 3: Savings Estimation of the Proposed Solution through Envelope Walls

<table>
<thead>
<tr>
<th></th>
<th>U-Value (W/m².K)</th>
<th>R-Value (1/U-Value)</th>
<th>Lost (kW)</th>
<th>Lost($)</th>
<th>Saved($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As Built</td>
<td>1.56</td>
<td>0.64</td>
<td>6049.56</td>
<td>$786.44</td>
<td>$0.00</td>
</tr>
<tr>
<td>Exterior Insulation (A)</td>
<td>0.721</td>
<td>1.39</td>
<td>2795.98</td>
<td>$363.48</td>
<td>$422.96</td>
</tr>
<tr>
<td>External Façade Wall (B)</td>
<td>0.48</td>
<td>2.08</td>
<td>1861.40</td>
<td>$241.98</td>
<td>$544.46</td>
</tr>
</tbody>
</table>

Table 4: Savings Estimation of the Proposed Solution through Structural Joints

<table>
<thead>
<tr>
<th></th>
<th>Psi-Value (W/m.K)</th>
<th>Lost (kW)</th>
<th>Lost($)</th>
<th>Saved($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Default</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balcony</td>
<td>0.515</td>
<td>277.36</td>
<td>$36.06</td>
<td>$0.00</td>
</tr>
<tr>
<td>Edge</td>
<td>0.576</td>
<td>710.00</td>
<td>$92.30</td>
<td>$0.00</td>
</tr>
<tr>
<td>(A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balcony</td>
<td>0.092</td>
<td>49.55</td>
<td>$6.44</td>
<td>$29.62</td>
</tr>
<tr>
<td>Edge</td>
<td>0.079</td>
<td>97.38</td>
<td>$12.66</td>
<td>$79.64</td>
</tr>
<tr>
<td>(B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balcony</td>
<td>0.142</td>
<td>76.48</td>
<td>$9.94</td>
<td>$26.11</td>
</tr>
<tr>
<td>Edge</td>
<td>0.03</td>
<td>36.98</td>
<td>$4.81</td>
<td>$87.49</td>
</tr>
</tbody>
</table>

Based on the above results, total savings were found to be $658 per year for scenario (A) and $532 for scenario (B). Accordingly, with the installation costs of the solutions being at $6750 and $6050, investment returns become approximately 10.5 and 11.5 years, respectively.

Conclusions, Recommendations, and Future Work

The lack of regulations in Lebanon regarding the thermal efficiency of buildings has resulted in excessive energy expenditure for the sole purposes of heating and cooling. Therefore, this research work studied the thermal performance of a typical 3-story residential building through 2-D and 3-D simulations on HTFlux and Autodesk CFD. Critical sections were analysed under the existing as-designed scenario against the suggested integrated solutions in order to identify the most appropriate or efficient result; whereby, this particular solution has been defined as the one that provided the most thermal resistivity and thermal comfort whilst being the most cost efficient.

As such, on the basis of the thermal insulation of the walls themselves, four different scenarios were developed and are ordered from least efficient to most efficient (1 to 4) as shown below:

1. Wall insulation: in place of air gap
2. Continuous external façade wall
3. Wall insulation: interior face of walls
4. Wall insulation: exterior face of walls

Air was found to be less conductive than EPS, and as such, leaving the air voids leads to greater thermal resistivity values. However, where the initial design is a single wall construction, it is recommended to apply an external façade wall rather than the suggested exterior face insulation to achieve greater heat retention. As for interior and exterior wall insulation placement, their resulting U-Values were the same; however, and considering that the building is residential, external insulation has shown to achieve greater comfort on the long run.

Regarding the case of thermal bridges, the solutions are ranked as follows:
1. Wall insulation: exterior face of wall
2. Installation of thermal break
3. Continuous façade wall

In this case, it was found that resorting to an external insulation or an external façade wall would both result in a payback period of 10.5 and 11.5 years, respectively. Moreover, and when accounting for the health benefits and thermal comfort that are also yielded in these two directions, it proves further that the proposed solutions are highly feasible.

Future work aims at expanding the study over other areas in Lebanon and the region as well as designing a detailed occupant comfort model and integrating it within the overall simulation.

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A comparative simulation of thermal performance in high-rise structural timber buildings

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Abstract: Current building science research is focusing more effort on residential occupant comfort analyses, particularly regarding summertime overheating in buildings that do not utilize mechanical air-conditioning. This paper presents a comparative study using whole-building energy model simulation data to examine occupant comfort in high-rise residential buildings constructed with cross-laminated timber structures and operating without mechanical cooling or heating. The research focuses on a comparative simulation of thermal performance in high-rise structural timber buildings. The study also discusses the influence of the cladding materials on the performance of the case study buildings. Two existing UK buildings (Bridport and Stadthaus) are modelled, validated, and simulated for summer conditions using a typical reference year weather file; the buildings are similar structurally, but exhibit different envelope systems and room dimensions. The resulting indoor conditions are compared for temperature values (average, minimum, and maximum), thermal comfort standards (CIBSE and BSEN 15251), and for correlation between indoor and outdoor temperatures. The Bridport building, which utilizes a brick façade, larger windows, and rooms, exhibits a wider range of temperatures during the study period (9.0°C) as well as more hours within acceptable comfort standards. The Stadthaus building, which utilizes a fibre cement siding, smaller windows, and short rooms, exhibits a small range of temperatures (8.2°C), but did exceed comfort levels for both the CIBSE and BSEN standards. Both building models show a strong correlation between indoor and outdoor temperatures for both day and night. Overall, this simulation demonstrates that an envelope with more thermal mass, such as brick, helps minimize the maximum temperatures, while the size of the rooms and windows might increase the temperature range in the space.

Keywords: Whole-building energy modelling and simulation, high-rise structural timber buildings, thermal behaviour, design parameters, comparative study

Introduction

In the last four decades, numerous studies have been conducted to understand thermal behavior of buildings as it relates to thermal comfort and energy performance of non-residential buildings (Rupp et al., 2015). Many of these studies led to the creation of energy efficiency and green building standards such as LEED rating system, the International Green Construction Code, and the ASHRAE 189.1 high-performance building standard (ASHRAE, 2014; ICC, 2012; USGBC, 2017). However, in the last two decades, studies have begun to focus more on the thermal behavior of residential buildings due to lack of data on occupant thermal comfort and the performance of building envelopes (Adekunle and Nikolopoulou, 2016; Dengel and Swainson, 2012; Sakka et al., 2012). Similarly, recent studies investigate thermal behavior of green/sustainable buildings including low-rise and high-rise buildings to understand how they perform in different seasons (Rijal and Stevenson, 2010; Adekunle and Nikolopoulou, 2014, 2016, 2017, 2018). Summer analyses are common in residential comfort studies due to the possibility of summertime overheating within the buildings, which are not always mechanically cooled (Rijal and Stevenson, 2012; Lomas and Kane, 2013; Adekunle and Nikolopoulou, 2016).

Structural timber is considered in this study over other major building materials such as concrete and steel due to its green credentials, biodegradable, lightweight, workability, ability
to be prefabricated into smaller components, easy to transport, quick to assemble, aesthetic appearance and ability to sequester carbon over its lifetime (Dewsbury and Nolan, 2015; Adekunle and Nikolopoulou, 2016). A study by Rijal and Stevenson evaluated summertime performance of a low-rise structural timber building and indicated the frequent use of controls to improve occupants’ comfort in structural timber buildings (Rijal and Stevenson, 2010). Similarly, the thermal behavior of both a low-rise housing development (145-dwelling units) built with structural insulated panels (SIPs) and a high-rise building constructed with cross-laminated timber (CLT) was considered in another study (Adekunle and Nikolopoulou, 2016). The latter study found that buildings constructed with CLT demonstrated greater thermal performance than buildings built with SIPs. None of these studies focused solely on the evaluation of the thermal behavior of high-rise structural timber buildings. Similarly, other studies on the topic investigate various building construction types (Leo Samuel et al., 2017; Puri et al., 2017) but also indicate a research gap exists regarding understanding occupant thermal comfort in different residential building construction typologies (Lomas and Kane, 2013; Gupta and Gregg, 2013). As a result, this study addresses this gap by considering a comparative analysis based on whole-building energy modeling and simulation to understand thermal behavior of high-rise structural timber residential buildings.

Most of the previous studies on thermal behavior considered various research methods to understand how buildings perform in different seasons (Rijal and Stevenson, 2010). For instance, Adekunle and Nikolopoulou (2016) considered post-occupancy evaluations (POE) including on-site measurements and subjective questionnaire supplemented with whole-building energy modeling and simulation. In other studies, environmental monitoring supplemented with whole-building energy modeling and simulation was explored (Rijal et al., 2007; Gupta and Gregg, 2013; Royapoor and Roskilly, 2015). Other studies considered on-site measurements as the main research methods supported with either subjective questionnaire (Rijal and Stevenson, 2010; Adekunle and Nikolopoulou, 2014, 2017) and observations during the investigations (Adekunle and Nikolopoulou, 2014). With these existing studies in mind, this study captures more data over a longer period than previous studies by utilizing a whole-building energy modeling and simulation; without the energy model, the process would be laborious, time-consuming and expensive if such data were collected using only on-site measurements (Royapoor and Roskilly, 2015). Moreover, since other studies have presented their findings based on on-site measurements, it is important for this study to explore whole-building energy modeling and simulation to understand the more specific thermal behavior of high-rise structural timber buildings.

Past studies have also attempted to link various design parameters and thermal properties of building envelopes with thermal behavior of buildings (Tiwari et al., 1993; Oral et al., 2004). Thermal mass was identified as a contributing factor for the better performance of buildings built cross-laminated timber over buildings constructed with structural insulated panels (Adekunle and Nikolopoulou, 2016). Space standards have also been also identified as one of the crucial factors that could influence the performance of spaces in buildings (Adekunle, 2014). Space standards are defined as various units used to classify space needs and calculate a space’s usage in terms of a square meter or footage and associated costs. For instance, in the UK, various space standards such as the Parker Morris Standards, the Affordable Homes Standards, and the National House Building Council (NHBC) Standards have been developed at different times for classifying space needs and estimating space usage in terms of square meter and associated cost of construction (Adekunle, 2014). Use of windows for ventilation was identified as a crucial factor for improving thermal behavior of buildings.
As a result, this study intends to link various design parameters (such as floor area, floor-to-ceiling height) that have not been fully explored in past studies with the thermal behavior of structural timber buildings.

Thermal comfort of occupants within a building can be assessed by applying various models. ASHRAE Standard 55 recommended that for any building to provide the comfortable thermal environment for occupants, at least 80% of occupants must be satisfied with the thermal environment (ASHRAE, 2013). The ASHRAE Standard 55 also provides a range of temperatures 22.0-25.0°C at which occupants feel most comfortable. The Standard stresses further that when indoor temperatures exceed the upper range, depending on occupants’ ability to adapt to the thermal environment, they may be subject to discomfort. Similarly, the CIBSE thermal comfort model specifies that summertime temperatures within any building must not exceed 28.0°C for more than 1% of occupied hours (CIBSE, 2010). The CIBSE model explained that if summertime temperatures exceed the threshold for 28.0°C, summertime overheating is likely to occur in the building. The adaptive comfort model, as stated in the BSEN15251 standard, specified different categories for assessing occupant thermal comfort using measured or simulated temperatures (British Standards Institute London, 2008). The Categories (I, II, III, IV) have upper and lower indicators with temperatures below lower indicators suggesting cold discomfort and temperature above the upper thresholds indicating warm discomfort. For newly built and refurbished buildings, Category II is considered an acceptable level for assessing the thermal comfort envelope and risk of summertime overheating (British Standards Institute London, 2008). Since the case study buildings (newly built high-rise timber buildings) considered in this study fall within the Category II, the upper and lower indicators for BSEN 15251 Category II are explored to understand if simulated temperatures within case study buildings predict occupant warm or cold discomfort during summer months when no mechanical air-conditioning or heating is present.

The research discusses the comparative simulation of thermal performance in high-rise structural timber buildings by exploring the whole-building simulation. The study also presents its findings on the influence of space standards and cladding materials on the performance of the case study buildings in the summertime.

Case Study Buildings

The research considered and evaluated two high-rise structural timber buildings as case studies to understand the thermal behavior of structural timber buildings. The case study buildings, Bridport (BD) and Stadthaus (ST), are located in London, UK. Both case study buildings are within 0.5 mile (0.8 km) radius of each other. Both BD and ST utilize cross-laminated timber (CLT) for structural framing, but each building has different cladding materials constituting their respective thermal envelopes. High-quality bricks (brown and light brown) are used for cladding of BD (Willmott Dixon, 2011), while wood fiber cement cladding, comprised of 70% recycled wood and 30% of other materials such as cement, is considered for ST (Thompson, 2009; TRADA, 2009). Both buildings were constructed within last the ten years. Each of the buildings saved at least ten weeks of construction time due to prefabricated CLT panels used in the construction process. The buildings have won different awards in terms of their sustainability and good carbon footprints (Adekunle and Nikolopoulou, 2016).

Bridport (BD) is a modern social housing building in Hackney, East London and was completed in 2011. The building has a floor area of 4,220.0 m² with a total of eight (8) floors. The BD building is considered the largest CLT housing structure in the UK (Willmott Dixon,
2011) and one of its tallest timber residential buildings at 24.50 m. The building has different units comprising of 1-bed, 2-bed, 3-bed, (33 units) and 4-bed (8 units) as shown in Fig 1. In total, it has 41 apartments occupied by low-income and middle-income families. Structurally, BD is built with CLT panels from the ground floor to the seventh floor.

Figure 1. Model of BD housing development with existing nearby building

Stadthaus (ST) is a privately financed housing complex, illustrated in Figure 2, located in Murray Grove, Hackney, UK and is owned by two housing providers and was completed in 2009 (Waugh et al., 2010). It is the tallest high-rise CLT building in the UK at 29.75 m (Thompson, 2009; TRADA, 2009). The 9-story building contains twenty-nine (29) total apartments comprised of 1-bed, 2-bed, 3-bed, and 4-bed units; the total floor area of the building is 2,750 m². Nineteen (19) of the apartments at ST are privately owned, while the remaining ten (10) units are identified as either socially rented or shared ownership (Lowenstein, 2008; TRADA, 2009). The ground floor of ST is built with concrete while the first through eighth floors are constructed with CLT panels (Thompson, 2009). Table 1 provides a summary of the architectural and structural components of both case study buildings.

Figure 2. Model of ST housing development.
Table 1. Description and summary of the components and other features of the buildings

<table>
<thead>
<tr>
<th>Case study</th>
<th>U-values for the different components (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walls</td>
</tr>
<tr>
<td>Bridport (BD)</td>
<td>(0.14W/m²K)</td>
</tr>
<tr>
<td>U-values/</td>
<td>Description of materials</td>
</tr>
<tr>
<td>Description of materials</td>
<td>Brick cladding, insulation, CLT, gypsum board</td>
</tr>
<tr>
<td>Stadthaus (ST)</td>
<td>(0.16W/m²K)</td>
</tr>
<tr>
<td>U-values/</td>
<td>Description of materials</td>
</tr>
<tr>
<td>Description of materials</td>
<td>Wood fiber cement cladding, insulation, CLT, gypsum board</td>
</tr>
</tbody>
</table>

Methodology

The research employs whole-building energy modeling and simulation to generate data for a comparative analysis of the BD and ST buildings operating without mechanical cooling/heating under summertime weather conditions. Whole-building energy models simulate all of the heat flow (conduction, convection, and radiation) in and out of a building and can predict energy use and internal thermal conditions (Royapoor and Roskilly, 2015). The EnergyPlus simulation engine via the DesignBuilder (version 3.2.1) graphic user interface were both used to create the models for this research (DesignBuilder, 2009; Lawrence Berkeley National Laboratory, 2010). The analysis of the model simulations compares average and extreme internal operative temperatures, overheating hours, and calculated linear correlations of internal and external temperature for both buildings.

Before simulation of the buildings was conducted, the models generated need to be validated in comparison to the existing buildings. As discussed in previous studies (Lomas et al., 1997) model calibration should focus on peak temperatures and resulting measured, and simulated temperatures should fall within a range of 2.0°C. Previous research validated the BD energy model using on-site measurements of environmental parameters (temperature and humidity) recorded during a 2-week peak-temperature period in July 2012 (Adekunle and Nikolopoulou, 2016); therefore, an extensive validation study is not included in this work.

The whole-building energy model simulations for this paper utilize a weather data file for London, Islington for the 2000s; this weather file was produced using the weather generator program from a UK research group (Eames, Kershaw, and Coley, 2011). For the summertime simulation, the data from July 1st to August 31st for the 2000s (Test Reference Year – TRY) was considered since both months are considered as the hottest months of the year. In addition, since the case study buildings have similar construction material typologies, most of the energy model construction input parameters considered for BD and ST are the same; Table 2 illustrates all the input parameters used to create the two models. The energy models were constructed using multi-zone divisions to represent individual rooms within each housing unit (kitchen, living area, bedrooms) as well as common spaces (stairs, storage areas, and lobbies). Shading obstructions included balconies and neighboring buildings but did not include vegetation.
Table 2. Description of parameters input for modeling and simulation of the buildings

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Bridport (BD)</th>
<th>Stadhuas (ST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating required</td>
<td>Heating is not considered in summer</td>
<td>Heating is not considered in summer</td>
</tr>
<tr>
<td>Heating setpoint/setback temperatures required</td>
<td>Setpoint/setback temperatures not needed</td>
<td>Setpoint/setback temperatures not needed</td>
</tr>
<tr>
<td>Ventilation required</td>
<td>Natural ventilation-heating/cooling not considered</td>
<td>Natural ventilation-heating/cooling not considered</td>
</tr>
<tr>
<td>Natural ventilation rate (per person)</td>
<td>9.0 l/s</td>
<td>9.0 l/s</td>
</tr>
<tr>
<td>Density (people/m²)</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Floor area of the building (m²)</td>
<td>4,220m²</td>
<td>2,750m²</td>
</tr>
<tr>
<td>Cooling setpoint/setback temperatures required</td>
<td>No setpoint/setback temperatures</td>
<td>No setpoint/setback temperatures</td>
</tr>
<tr>
<td>Day-time considered</td>
<td>8am – 10pm</td>
<td>8am – 10pm</td>
</tr>
<tr>
<td>Night-time considered</td>
<td>11pm – 7am</td>
<td>11pm – 7am</td>
</tr>
<tr>
<td>General lighting required</td>
<td>2.0W/m²</td>
<td>2.0W/m²</td>
</tr>
<tr>
<td>Task and display lighting required</td>
<td>0.5W/m²</td>
<td>0.5W/m²</td>
</tr>
<tr>
<td>Metabolic (activity)</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Metabolic (clothing)</td>
<td>0.5clo</td>
<td>0.5clo</td>
</tr>
<tr>
<td>Estimated infiltration (ac/h)</td>
<td>0.12ac/h</td>
<td>0.12ac/h</td>
</tr>
<tr>
<td>Estimated outside air change rate (ac/h)*</td>
<td>5.0ac/h</td>
<td>4.0ac/h</td>
</tr>
<tr>
<td>Equipment (such as computers)</td>
<td>3.9W/m²</td>
<td>3.9W/m²</td>
</tr>
<tr>
<td>Window to wall ratio</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Window height</td>
<td>2.1m</td>
<td>1.75m</td>
</tr>
<tr>
<td>Floor-to-ceiling height</td>
<td>2.65m</td>
<td>2.35m</td>
</tr>
<tr>
<td>Thermal zone</td>
<td>Multi-zone</td>
<td>Multi-zone</td>
</tr>
<tr>
<td>Occupation schedules</td>
<td>Varied</td>
<td>Varied</td>
</tr>
<tr>
<td>Shading objects; adjoining buildings</td>
<td>West, Northwest</td>
<td>None</td>
</tr>
</tbody>
</table>

* Most of the spaces in BD are cross-ventilated with higher window height, while most of the spaces in ST are single-sided ventilated.

The study predominately compares the thermal performance of two envelope and cladding systems as they relate to mid-rise residential buildings constructed with CLT structural systems and operating under un-conditioned summertime conditions. The initial phase of the analysis compares the resulting predicted average, maximum, and minimum indoor operative temperatures from both buildings. Similarly, each simulated building is evaluated for indoor overheating using the CIBSE thermal comfort model and the BSEN 15251 adaptive comfort overheating criteria (British Standards Institute London, 2008); this method has been demonstrated in thermal comfort simulations in previous studies by (Adekunle and Nikolopoulou, 2016). Finally, the comparative analysis of the model simulations calculates the linear correlation of internal operative and external dry-bulb temperature in order to compare the building variations (cladding and floor-to-ceiling heights) with a common variable (external conditions). Linear regression normalizes the analysis by comparing simulated indoor conditions from both buildings with similar outdoor condition regardless of time. Finally, the study then compares the difference and range between the two resulting regression lines.
Results

The simulated data for both BD and ST was generated for a period of July-August (1,488 hours). The TRY weather file data indicates that the average external temperature for the period considered is predicted to be 17.5°C and includes a maximum temperature of 28.4°C on July 29 and a minimum temperature of 8.1°C on August 22 as shown in Figure 3. For the BD building, the predicted average internal temperature is 21.4°C while the predicted maximum and minimum temperatures are 27.3°C and 16.8°C respectively. For ST, the predicted average internal temperature is 22.3°C, while the predicted maximum and minimum temperatures are 27.7°C and 18.7°C respectively. Table 3 provides a summary of the predicted average, maximum, and minimum internal and external temperatures for different durations of the simulation including the estimated date for each value. Generally, the analysis of the resulting data indicates higher temperatures are predicted in ST than in BD.

Table 3. Summary of the predicted temperatures for various periods of the simulation at the case study buildings

<table>
<thead>
<tr>
<th>Simulated temperatures</th>
<th>Bridport (BD)</th>
<th>Stadthaus (ST)</th>
<th>External Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average temperature</td>
<td>21.4°C</td>
<td>22.3°C</td>
<td>17.5°C</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>27.3°C</td>
<td>27.7°C</td>
<td>28.4°C</td>
</tr>
<tr>
<td>Minimum temperature</td>
<td>16.8°C</td>
<td>18.7°C</td>
<td>8.1°C</td>
</tr>
<tr>
<td>Average day-time</td>
<td>22.2°C</td>
<td>23.0°C</td>
<td>19.3°C</td>
</tr>
<tr>
<td>Maximum day-time</td>
<td>27.3°C</td>
<td>27.7°C</td>
<td>28.4°C</td>
</tr>
<tr>
<td>Minimum day-time</td>
<td>17.5°C</td>
<td>19.3°C</td>
<td>9.2°C</td>
</tr>
<tr>
<td>Average night-time</td>
<td>20.2°C</td>
<td>21.0°C</td>
<td>14.5°C</td>
</tr>
<tr>
<td>Maximum night-time</td>
<td>24.1°C</td>
<td>24.5°C</td>
<td>21.7°C</td>
</tr>
<tr>
<td>Minimum night-time</td>
<td>16.8°C</td>
<td>18.7°C</td>
<td>8.1°C</td>
</tr>
</tbody>
</table>

*The date for the predicted average internal and external temperature for different periods considered for the analysis cannot be determined.

Figure 3. Chart showing simulated temperature and day/time for the simulated period at the buildings.
The second comparison evaluates the models in regards to the CIBSE ‘Guide A’ thermal comfort model and the BSEN 15251 adaptive comfort model (CIBSE, 2006; British Standards Institute London, 2008). The CIBSE ‘Guide A’ thermal comfort standard recommends building indoor conditions not exceed 28.0°C for more than 1% of a year. For the simulations of BD and ST, the predicted external temperatures were below 28.0°C for the entire simulated period. Simulated indoor temperatures at BD are above 25.0°C for 4% (55 hours) of the time; however, at ST, the simulated indoor temperature does exceed 25.0°C for approximately 8% (111 hours) of the simulation period. The temperature did not rise above the 28.0°C for more than 1% of the time in either of the buildings.

Each building was also evaluated in relation to the BSEN 15251 adaptive thermal comfort model Category II (new construction) (British Standards Institute London, 2008). At BD, the predicted temperature was acceptable, as it did not rise above the Category II upper indicator for more than 5% of the time. However, the predicted temperatures at ST do rise above the Category II upper indicator for more than 5% of the time. This part of the analysis further confirmed the possibility of high temperatures to be predicted within spaces of high-rise structural timber buildings.

**Discussions**

Both building simulations predict July 29 as the warmest day for the simulation period (July-August of the 2000s) with an average external daily temperature of 23.7°C; this average daily temperature is 6.2°C higher than the average external temperature 17.5°C for the total simulation period. The results show the possibility of frequent high external temperatures that can influence the thermal behavior of sustainable buildings; this is of concern for buildings with low thermal mass such as high-rise timber buildings. The lowest temperatures are predicted on August 21 with the external daily temperature of 15.4°C showing a difference of 21.0°C lower than the average external temperature.

Table 3 illustrates that the findings reveal higher average internal temperatures predicted for ST compared to BD for the whole simulation period, day-time periods, and night-time periods. Moreover, the predicted average, maximum, and minimum temperatures tend to be higher by a range of 0.4-1.9°C at ST than BD. Comparing the results with the design of ST and BD, it should be noted that typical BD residential rooms have larger floor area and higher floor-to-ceiling height than spaces at ST. Additionally, the spaces and the size of openings tend to be a contributing factor to much cooler internal conditions predicted at BD than ST.

The regression analysis to establish a relationship between the simulated external temperature and internal temperature at the buildings revealed strong correlations are found between the two temperatures (internal and external) at both case study buildings (Figure 4). The R² values of 0.8808 and 0.8851 are predicted for BD and ST respectively. The significance is also reported in the buildings as the predicted internal temperatures increase when the external temperatures rise. The correlation shows the possibility of temperature swing within a wide range at the case study buildings. The ST building is predicted to be warmer than BD with the predicted temperatures over a range of 8.2°C, while BD has a predicted temperature range of about 9.0°C. Indoor temperature is predicted to be within the comfort range of 22.0-25.0°C when the predicted external temperature is within a range of 18.0-24.0°C. Internal temperatures tend to drop at a faster rate in ST than in BD, while it takes a long time for internal temperatures to be predicted above the comfort range in both BD and ST. One of the factors contributing to the thermal behavior of BD is the ability of the cladding materials used for BD (high-quality brown bricks) to provide additional thermal mass to the building.
envelope; whereas the wood fiber cement tiles that clad ST likely reduce temperature swings within the thermal environment. The correlation shows the external temperature is a major parameter that influences the predicted internal temperature within the buildings.

**Figure 4.** Regression analysis between simulated internal temperature and external temperature (July-Aug)

Further analysis of simulated day-time temperatures shows that a strong correlation exists between the day-time internal and external temperatures for both buildings (Figure 4). The findings show the $R^2$ value of 0.8457 is predicted between the simulated internal temperature and the external temperature at BD while the $R^2$ value of 0.8480 is predicted between the variables at ST. The correlation shows the external temperatures strongly influence the simulated internal temperatures. However, a stronger correlation is predicted between the variables at ST. The building (ST) is predicted to be much warmer than BD with temperatures being at least 0.3°C higher than BD at any specific time. Occupants living in BD are likely to experience a wider range of predicted temperatures (about 9.1°C) when compared to ST 8.1°C; this is likely due to the building envelope of BD reducing the rate of heat flow when compared to the ST building envelope. Additionally, since BD has taller openings and floor to ceiling heights than ST, spaces at BD may take longer to overheat due to internal convection even during hot summer days. Considering the design of BD, occupants may likely use thermal controls (such as air-conditioning) more regularly than occupants living at ST. During the daytime, nearby buildings also tend to provide shade on BD, which also reduce external heat gains into the building and thereby improves the overall thermal conditions of the buildings.
Figure 5. Regression analysis between simulated day-time temperature and external temperature (July-Aug)

For the nighttime evaluation, $R^2$ values of 0.8047 and 0.8120 for BD and ST in that order. The correlation shows a change in the external temperatures results in a change in the internal temperatures. The findings show simulated internal temperature ranges are similar to daytime ranges in that BD has a slightly larger temperature range than ST 4.0°C as shown in Figure 6. However, this finding is contrary to the much wider range of temperatures predicted at BD and ST during the daytime. However, there is a possibility of higher temperatures to be predicted in the buildings when the external temperatures are elevated as they are in the daytime. Also, the night-time simulated temperature showed the possibility of occupants in high-rise structural timber buildings experiencing warm discomfort during the sleeping period; this is more apparent at ST than at BD. The results showed variations in the ability of occupants to adapt to the thermal environment of the buildings. The findings showed the possibility of occupants adapting to a wide range of temperature during daytime and vice-versa at night-time. The results show a risk of summertime overheating, even at nighttime, in high-rise timber buildings. Strong correlations also exist between the simulated internal and external temperatures during nighttime. The correlations show the external temperature dictates the internal temperature during summertime at the case buildings due to the low thermal mass of the building envelope as highlighted in the previous study (Adekunle and Nikolopoulou, 2016).
Regarding the analysis on thermal comfort models (the CIBSE and the adaptive comfort), the results revealed that summertime overheating is predicted in spaces at ST for the simulation period, while only the possibility of summertime overheating is identified at BD. The findings showed the predicted temperature rise above 25.0°C for 8% at ST while it is only predicted to rise above that indicator for 4% at BD. The findings showed summertime overheating is predicted at ST although the weather data file considered is the test reference year (TRY) and not the design summer year (DSY) weather file; the DSY files are more appropriate for evaluating extreme summertime overheating in buildings. For the BSEN 15251 adaptive comfort model, the results showed warm discomfort is predicted at ST due to the simulated temperature rising above the Category II upper indicator more than 5% of the time. It is also important to note that warm discomfort is not predicted at BD. However, cold discomfort is predicted possible due to the generally bigger rooms in BD. When lower temperatures are predicted at BD, the findings show that indoor rooms take longer to get warm and attain temperature within comfort range than spaces at ST. As a result, cold discomfort is predicted possible at BD and not at ST, especially at nighttime. The result also showed that high-rise structural timber buildings with bigger floor areas, high floor-to-ceiling heights, larger area of openings, and cladding material with higher thermal mass tend to perform better in regards to obtaining acceptable occupant comfort levels when they are evaluated using adaptive thermal comfort model.

Even though both case study buildings BD and ST are constructed with CLT, the results show that cladding material and space standards are contributing factors to the thermal behavior of buildings. Additionally, other parameters such as the size of openings and interior finishes can significantly help to minimize the risk of summertime overheating in structural high-rise timber buildings. It appears orientation may be a contributing factor to the ST building being warmer than the BD building. As shown in Figure 1, the longer sides of the BD building are east facing and west facing while the ST building has almost equal four sides (Figure 2). The equal sides of the four orientations suggest the possibility of higher solar heat gains into the ST building during the day-time and evening period from the south, east and west orientations.
addition, the apartments at the east facing and south facing of the BD building are provided with balconies which can reduce penetration of the sun into the spaces. The west facing of the BD building also has an adjacent high-rise building which can also help in reducing the penetration of the sun during the evening time in summer. At the ST building, the north facing, and east facing are bounded by two existing roads while the open playground for the residents bounds the south facing of the building. The exposure of the ST building to additional solar heat gains may contribute to higher temperatures predicted at the building.

In terms of limitations, this study has limitations in that it only focuses on two building in a rather moderate climate. Given the fact that CLT construction is a newer technology, additional research is needed, as building examples, arise to evaluate CLT structures perform in more extreme hot and cold climates. Furthermore, an in-depth review of the simulation data from this paper indicates higher temperatures are predicted on the upper floors of the buildings; further research is required to understand thermal behavior of structural timber buildings at different floor levels. Also, further research on building modeling to show a comparison between the case study buildings and concrete (heavyweight) structures of a similar size will be considered. The outcome will help to draw a strong comparison between the thermal performance of the buildings constructed with different building materials.

Conclusions
This paper considered a study based on building simulation to understand the thermal behavior of high-rise structural timber buildings. The research methodology used in this study has been considered in existing studies in the field. However, the research is one of the first set of documented work in the subject area to discuss the comparative simulation of thermal performance in high-rise structural timber buildings. The research topic and the findings presented in the paper show the originality of the study to the body of knowledge. The study analyzed simulated data for the hottest summer period from July-August using TRY weather data. The findings showed higher average, minimum and maximum temperatures and wider temperature ranges are predicted at ST when compared to BD. The predicted temperatures at the buildings revealed occupants are likely to adapt to a wide range of temperature (at least 9.0°C) during summertime especially daytime. However, a shorter nighttime range of temperature 4.0°C is predicted at ST than BD 5.4°C indicating that occupants at ST may experience warm discomfort during nighttime which can affect their overall thermal comfort during sleeping time.

Applying the CIBSE and BSEN 15251 thermal comfort models, summertime overheating is predicted at ST while BD is susceptible to summertime overheating if the predicted external temperature increases. Warm discomfort is predicted at the ST with the simulated temperature rise above 5% of the time above the Cat. II upper level. Cold discomfort is also predicted at BD when the predicted external temperature drops below 14.0°C.

Finally, the study showed that the thermal behavior of high-rise timber buildings is directly influenced by variations in design parameters and cladding materials. The results provide an understanding that occupants living in high-rise buildings may be subject to a different range of temperatures when these parameters are taken into consideration. The study helped to identify that summertime overheating is predicted in high-rise timber building when the external temperature increases and the possibility of cold discomfort when the external temperature drops. Overall, this simulation demonstrates that an envelope with more thermal mass, such as brick, helps minimize the maximum temperatures, while the size of the rooms and windows might increase the temperature range in the space. The paper
explained different design interventions that can be explored to minimize the effect of summertime overheating in high-rise structural timber buildings as the global and regional temperature increases in the coming years.

References
Lawrence Berkeley National Laboratory [LBNL] (2010). Energy-Plus documentation V6.0 (October), Berkeley, CA: LNBL.


Energy Performance Analysis of Large-Scale Public Buildings in China

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² Engineer, Building Services, Ove Arup & Partners Hong Kong Limited

Abstract
China is now one of the fastest-growing countries in the world, where the increase in urbanisation rate is rapid. In order to accommodate the fast-growing urban population, which increased from 17.9% to 54.8% from 1978 to 2014, it is estimated that approximately 2 billion m² of new buildings will be constructed each year, which is the sum of all in developed countries. The drawback of such rapid growth in building developments, China’s total energy consumption increased from 0.57 billion tons of standard coal to 4.3 billion tons of standard coal from 1978 to 2015. In order to improve the existed environmental issues such as global warming and air pollution, which are threatening human’s health in some of the major cities in China such as Chengdu, Beijing and Shanghai, it is doubtless that improvement in building energy performance has the immediate need. More importantly, large-scale public buildings are found to consume a large portion of total energy in China. This paper therefore aims to (1) perform a thorough review of the current situation of the energy performance of large-scale public buildings in China; (2) investigate the reasons of high energy consumption in large-scale public buildings in China. Through the literature review, it found that China’s large-scale public buildings account less than 4% of the total urban construction area, but their energy consumption accounts for about 22% of the total energy consumption in urban construction area. Its energy use intensity is about 10 times of the residential building and 7 times of the public building. Large-scale shopping mall has the highest energy use intensity among different types of large-scale public buildings.

Keywords: Large-scale Public Buildings, Building Energy Performance

1. Definition of Large-Scale Public Buildings in China

In China, buildings are categorised into civil and industrial building (Shui & Li, 2012). In civil building, it’s further categorised into residential buildings and public buildings. The public buildings consist of commercial buildings, government buildings, college, hospital, hotel and other non-residential buildings except plants and factories. The commercial buildings include office, shopping mall, financial and mixed-use buildings. The public buildings with total floor area larger than 20,000m² is classified as large-scale public buildings. (Hong, Li, & Yan, 2015) (Jiang P., Analysis of national and local energy-efficiency design standards in the public building sector in China, 2011) (Jiang, Chen, Dong, & Huang, 2014) (Allouhi, et al., 2015) (Li J., 2016). The building types in China is summarised in Figure 1 - Building Category in China.
In this paper, the large-scale public building to be studied is the commercial building with total floor area larger than 20,000m². There are examples of large-scale commercial buildings in China as shown in Table 1 - Examples of Large-scale Commercial Buildings in China.

<table>
<thead>
<tr>
<th>Building</th>
<th>Location</th>
<th>Building Type</th>
<th>Office</th>
<th>Financial</th>
<th>Mixed-use</th>
<th>Civil</th>
<th>Public</th>
<th>Residential</th>
<th>Hotel</th>
<th>Commercial</th>
<th>Government</th>
<th>College</th>
<th>Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shanghai Tower</strong></td>
<td>Shanghai</td>
<td>Mixed-use with shopping mall and office</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plaza 66</strong></td>
<td>Shanghai</td>
<td>Mixed-use with shopping mall and office</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Zhengjia Commercial Mall</strong></td>
<td>Guangzhou</td>
<td>Mixed-use with shopping mall, office and hotel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
International Finance Centre  
Location: Guangzhou  
Building Type: Mixed-use with office, hotel and finance centre  
https://en.wikipedia.org/wiki/Guangzhou_International_Finance_Center

Parkview Green  
Location: Beijing  
Building Type: Mixed-use with shopping mall, office and hotel  
http://www.igreen.org/uploadfile/2012/0922/20120922105642868.jpg

Hysan Place  
Location: Hong Kong  
Building Type: Mixed-use with shopping mall and office  
http://www.wikiwand.com/en/Hysan_Place

Table 1 - Examples of Large-scale Commercial Buildings in China

2. Current Status of Energy Performance of Large-Scale Public Buildings in China

Tsinghua University studied the energy consumption performance of buildings in China in 2007. It collected the actual energy consumption data and area of different types of buildings in China. According to the statistical data collected by Tsinghua University (Energy Research Institute National Development and Reform Commission, 2007) (Tsinghua University Building Energy Research Center, 2011) (Building Energy Conservation Research Centre, Tsinghua University, 2013) (Wang, Yu, & Yang, 2009) (Wang, Shao, & Han, 2010) (Qiang, 2011) (Chen & Li, 2005) (Li J. S., 2008) (Jiang L., 2016) which is summarised in Table 2 - China’s Urban Building Energy Classification and Consumption, China’s large-scale public buildings account less than 4% of the total urban construction area, but their energy consumption accounts for about 22% of the total energy consumption in urban construction area. The average energy intensity of the large-scale public building is the highest, it is about 10 times of the residential building and 7 times of the public building.
<table>
<thead>
<tr>
<th>Area (hundred million m²)</th>
<th>Residential Building</th>
<th>Public Building</th>
<th>Large-scale Public Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>55</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Energy Consumption (hundred million kWh)</td>
<td>2000</td>
<td>1600</td>
<td>1000</td>
</tr>
<tr>
<td>Average Energy Intensity (kWh/m²)</td>
<td>20</td>
<td>29</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 2: China’s Urban Building Energy Classification and Consumption (Energy Research Institute National Development and Reform Commission, 2007)

Tsinghua University also carried out survey to study the energy consumption behaviour of different type of large-scale buildings in Beijing. According to the surveyed result as shown on Figure 2 (Energy Research Institute National Development and Reform Commission, 2007), the building area for most of the large-scale public buildings concentrates on 0-100,000m² range. In this area range, the large-scale shopping malls have the highest energy usage. Also, it is also observed that the larger the building area, the higher is the energy use.

The energy consumption performance of large-scale public building in China was studied by researchers. From literature reviews (Liu, 2012) (Lei, 2013) (Wan, 2016) (Zhang X., 2008) (Zhang J., 2013) (Feng, 2016) (Wan, 2016), the energy consumption intensity of different type of large-scale public buildings in China is summarised in Figure 3. The researchers carried out survey on existing buildings to get their actual energy consumption data. Three key findings are found from the literatures and they are summarised in below.

1. Figure 3 summarised the energy consumption of different types of large-scale building in different climate zones of China. It is found that the large-scale shopping mall has highest energy use intensity among different large-scale building types in China. It is about 2.5 times of mixed-use building, 2.4 times of institution and office...
1. Building, 2.2 times of hospital and educational building, 1.5 times of hotel and 1.4 times of public health buildings.

2. From those literatures, large-scale shopping malls in hot summer warm winter (HSWW) climate zone has the highest energy use intensity.

3. HVAC and lighting systems are the two biggest energy components, they account around 50%-80% of the total building energy.

To conclude, the large-scale shopping mall has the highest energy consumption intensity among different building type in China. Therefore, in order to reduce the building energy consumption, focus shall be put on the energy saving strategy on large-scale shopping malls in China.

3. Reasons for High Energy Consumption in Large-Scale Shopping Mall in China

What leads to the high energy consumption in large-scale shopping mall? Literatures were reviewed to identify the reasons for the high energy consumption in large-scale public shopping mall and they are analysed and summarised in Table 4.
<table>
<thead>
<tr>
<th>Reasons</th>
<th>Literatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping mall has longer opening / operation hours - average 12-13 hours a day, and they are open throughout the year.</td>
<td></td>
</tr>
<tr>
<td>In addition, due to the large internal heat generation, the air-conditioning operation time is also longer than that of other buildings. Shopping malls in Beijing are usually use the all air system, air handling unites operate the year-round, so the fan electricity consumption is the largest proportion total electricity consumption in air-conditioning system, it accounts for 65.4% of the shopping mall's total electricity consumption in air-conditioning system. In general, the air conditioning system uses 50% of the total electricity consumption, followed by lighting electricity accounts for 40% of the total electricity consumption, the remaining 10% for the elevator.</td>
<td>(Energy Research Institute National Development and Reform Commission, 2007) (Wang, Shao, &amp; Han, 2010)</td>
</tr>
<tr>
<td>In winter time, to maintain the comfort level, air-conditioning systems needed to operate for long hours.</td>
<td>(Chen C., 2016)</td>
</tr>
<tr>
<td><strong>2. High Occupancy Rate</strong></td>
<td>(Liu, 2012) (Zhang J., 2013) (Chen C., 2016)</td>
</tr>
<tr>
<td>The occupancy rate in shopping mall is higher. Higher the occupancy rate, higher is the internal heat gain to building from occupant, so more air-conditioning energy is required to remove and maintain comfort conditioning inside the shopping mall.</td>
<td></td>
</tr>
<tr>
<td>In shopping mall, they have extra lighting system that other building types do have. Display lighting for products / advertisement display; decorative lighting for creating nice and stylish environment, during the festival period, there are more decorative lighting; external façade lighting for creating attractive image to entice people to get into the shopping mall.</td>
<td></td>
</tr>
<tr>
<td>Reasons</td>
<td>Literatures</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>These lighting systems consume extra energy. This also increases the</td>
<td>(Wang, Shao, &amp; Han, 2010)</td>
</tr>
<tr>
<td>energy consumption for air-conditioning system as they contribute to</td>
<td>(Liu, 2012)</td>
</tr>
<tr>
<td>internal heat gain which has to be removed by air-conditioning system.</td>
<td></td>
</tr>
</tbody>
</table>

4. **High Internal Heat Gain**

Shopping mall has higher internal heat gain which includes lighting, people and equipment load when compared with other building type. It results in higher demand for air conditioning.

(Wang, Shao, & Han, 2010)

5. **Utilisation of Glass Structure**

Shopping mall adopts glass curtain wall which uses more glass façade than other buildings. Some are designed without careful consideration of the shading and thermal insulation. This leads to more heat transfer between internal and external environments and so increases the building cooling demand.

With the economic development, people have been pursuing the luxury architectural design which causes energy wastage. This phenomenon has been becoming increasingly serious.

Glass façade is a common design for large-scale shopping malls, mixed-used buildings and office buildings in Shenzhen (HSWW Climate Zone). The percentage of façade area that uses glass is 33.04% for large-scale shopping malls, while that for office buildings, mixed-used buildings, hotel buildings and government buildings are 39.84%, 43.18%, 17.57% and 17.52% respectively. (based on 1062 surveyed buildings in Shenzhen).

According to the survey in Shenzhen (HSWW Climate Zone) buildings, the energy used in the air-conditioning system for offsetting the heat from sun accounts for more than 4% of the total energy consumption.

Therefore, some experts pointed out that the buildings in Southern part of China should focus on the sun-shading on

(Wang, Shao, & Han, 2010)
<table>
<thead>
<tr>
<th>Reasons</th>
<th>Literatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>the west, south and east façade and the strictly control the</td>
<td></td>
</tr>
<tr>
<td>adoption of large glass curtain wall.</td>
<td></td>
</tr>
<tr>
<td>6. Cooling and Lighting for Basement Shopping Mall</td>
<td>(Liu, 2012)</td>
</tr>
<tr>
<td>Basement shopping malls usually have higher requirements on cooling</td>
<td></td>
</tr>
<tr>
<td>system and lighting systems which lead to higher energy consumption</td>
<td></td>
</tr>
<tr>
<td>when compared to other types of buildings.</td>
<td></td>
</tr>
<tr>
<td>7. Higher Comfort Requirement</td>
<td>(Lei, 2013)</td>
</tr>
<tr>
<td>According to research result, large-scale buildings in countries with</td>
<td></td>
</tr>
<tr>
<td>fast economic development consume more energy than countries with</td>
<td></td>
</tr>
<tr>
<td>lower level of development. This is because they have relatively</td>
<td></td>
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<tr>
<td>higher requirement on indoor thermal comfort. This leads to higher</td>
<td></td>
</tr>
<tr>
<td>energy demand.</td>
<td></td>
</tr>
<tr>
<td>8. Extra Functional Areas</td>
<td>(Yang)</td>
</tr>
<tr>
<td>There are special functional areas include restaurants, control</td>
<td></td>
</tr>
<tr>
<td>centres, kitchens, laundries, booth, ATM.</td>
<td></td>
</tr>
<tr>
<td>Electricity consumption in special functional area of a building</td>
<td></td>
</tr>
<tr>
<td>refers to the electricity consumption of electric equipment that is</td>
<td></td>
</tr>
<tr>
<td>not a part of the normal function of a building and is more related</td>
<td></td>
</tr>
<tr>
<td>to the special functional requirements of the building.</td>
<td></td>
</tr>
<tr>
<td>9. Inaccurate Building Energy Simulation</td>
<td>(Lei, 2013)</td>
</tr>
<tr>
<td>Inaccurate building energy estimation during the design stage due to</td>
<td></td>
</tr>
<tr>
<td>the improper assumptions and improper setting of simulation parameters.</td>
<td></td>
</tr>
<tr>
<td>According to research result from U.S New Building Council, setting</td>
<td></td>
</tr>
<tr>
<td>of simulation parameters has the greatest impact on the building total</td>
<td></td>
</tr>
<tr>
<td>energy consumption.</td>
<td></td>
</tr>
<tr>
<td>10. Not Following Design Codes or Regulation</td>
<td>(Lei, 2013)</td>
</tr>
<tr>
<td>Design and equipment installation are not in accordance with energy</td>
<td></td>
</tr>
<tr>
<td>efficiency design codes. This leads to higher loading demand estimation</td>
<td></td>
</tr>
<tr>
<td>during the design stage.</td>
<td></td>
</tr>
<tr>
<td>11. Lack of Natural Ventilation</td>
<td></td>
</tr>
<tr>
<td>In shopping mall, the external windows are basically can’t be open,</td>
<td></td>
</tr>
<tr>
<td>so natural ventilation cannot be achieved.</td>
<td></td>
</tr>
</tbody>
</table>

(Building Energy Conservation Research Centre, Tsinghua University, 2011)
<table>
<thead>
<tr>
<th>Reasons</th>
<th>Literatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>For example, the selection of lighting electrical products can’t meet the &quot;Green Light&quot; requirements. The computer, copiers, printers, refrigerators, freezers, drinking fountains also can’t meet the energy saving and energy efficiency requirements.</td>
<td></td>
</tr>
<tr>
<td><strong>13. Improper Maintenance of Equipment</strong></td>
<td>(Wang, Shao, &amp; Han, 2010)</td>
</tr>
<tr>
<td>The clogged dust increases the resistance in air handling unit, the efficiency is only around 40% to 50%. This is one of the reasons leading to high energy consumption in buildings.</td>
<td></td>
</tr>
<tr>
<td><strong>14. Lack of Motivation to Save Energy</strong></td>
<td>(Wang, Shao, &amp; Han, 2010)</td>
</tr>
<tr>
<td>Some of the large-scale public buildings consume very high energy because they are public usage and nobody is responsible for huge energy consumption, no penalty and punishment for huge energy consumption. Energy-efficient buildings will inevitably increasing costs and expenses for developers and users by adopting more energy saving design and equipment, however there are no subsidy to them.</td>
<td></td>
</tr>
<tr>
<td><strong>15. Difficult to Control the Energy Consumption in Tenant Areas and Difficult to Persuade Tenants to Adopt Energy Saving Measures</strong></td>
<td>(Wang, Shao, &amp; Han, 2010) (Jiang L. , 2016)</td>
</tr>
<tr>
<td>For example, in Shopping Mall, tenant pays bill lighting and other equipment energy consumption, landlord pays bill for air-conditioning energy. Tenant generally concern more about the interior design and decoration in order to attract customer rather than energy consumption. So it is difficult to control the tenant on designing their internal lighting. Feedbacks from exiting Building Operators and Managers in exiting three Shopping Malls (Two are in Hong Kong and one is in Cardiff)</td>
<td></td>
</tr>
<tr>
<td>In design stage, air conditioning equipment is generally over-sized, when it comes to actual operation, most of the time the equipment is operated at part load, which resulting in lower COP and so poorer performance. Generally large pump selection, will result in deviation from the best pump working point, most of the time the water system is running in the &quot;big flow, small temperature difference&quot; conditions, the pump power consumption is larger.</td>
<td></td>
</tr>
<tr>
<td><strong>17. Management and Policy</strong></td>
<td>(Wang, Shao, &amp; Han, 2010)</td>
</tr>
<tr>
<td>No penalty for the buildings which cannot meet the energy code requirements. Although the Ministry of Construction</td>
<td></td>
</tr>
</tbody>
</table>
Reasons | Literatures
---|---
has approved and promulgated 21 important national and industrial standards such as "Design Standards for Energy Efficiency in Public Buildings", it only stays in writing. Few projects are penalized for failing to meet energy conservation standards. | (Wang L., Yu, Ma, & Yang, 2011)
(Tsinghua University Building Energy Research Centre, 2007)

Lack of energy management, energy consumption monitoring, and energy conservation regulations | 4. Conclusion

China’s large-scale public buildings account less than 4% of the total urban construction area, but their energy consumption accounts for about 22% of the total energy consumption in urban construction area. The average energy intensity of the large-scale public building is the highest, it is about 10 times of the residential building and 7 times of the public building. Among different type of large-scale public buildings, large-scale shopping mall has the highest energy consumption intensity. It implies that in order to reduce the building energy consumption, focus shall be put on the energy saving strategy on large-scale shopping malls in China.

In this paper, the reasons for the high energy consumption have been summarised from different literatures. It helped to establish a better understanding of the causes of high energy consumption by the large-scale shopping malls in China. This paper has therefore established a direction for further study on the energy performance of large-scale shopping malls in China. In order to quantify the major causes of high energy consumption and identify the effective energy saving strategies, this paper suggests further study be carried out by setting up an energy simulation by picking real building example and to prioritize the significance of the identified reasons for high energy consumption of the shopping malls. Once the parametric relationships have been identified, different energy saving strategies shall be tested to provide an insight to achieve building energy performance optimization on large-scale shopping mall in China.

References


Comparative Study of energy consumption optimization for Educational buildings in Jordan

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² School of Architecture and Built Environment, German Jordanian University.

Abstract: This paper introduces a comparative study between energy consumption optimization of school’s sector for the all 8 orientations (N-S), (E-W), ((NE-SW) and (NW-SE), likened with a previous research (Al-Arja et al, 2015) energy consumption index. The study will be conducted in classrooms of public schools as a case study using Design Builder (DesignBuilder, 2011) as the thermal simulation program, to establish numerical comparisons for different parameters such as; orientation, window area, glass panes, thermal insulation, and solar protection devices. The link with the previous research (Al-Arja et al, 2015) will be through finding optimum construction solutions for new schools buildings to be built in Jordan, and establish a benchmark for thermal performance as the Energy Consumption Index for educational buildings in Jordan, as a hot-arid climate

Keywords: Orientation, Energy consumption Index, Thermal Simulation, Educational Building, Energy Efficiency.

Introduction

Background

New school building envelope designs are developed to meet the student’s and staff requirements without much concern to the local climate and with no objective to conserve energy, despite the fact that proper façade orientation should be taken into consideration when zoning functions and activities, early in the design process. An answer should be provided for an important issue; which building orientation makes the highest reduction in energy demand for school’s buildings in Jordan?. Preserving the valuable resources in our planet would be as a result when comfort and energy saving are important in the climate responsive design (La Roche et al, 2001). Thermal behaviour of a building is altered when it is laid out in different orientations. Building form, window surface area, and the building orientation determine solar heat gain into the building.

In this research, building orientation was used to determine relative efficiency of different base and skewed orientations in hot arid climate, Jordan as a case study. A study on the effect of orientation on building thermal performance (Al-Tamimi et al, 2011) shows that building orientation is a significant design consideration, mainly with regard to solar radiation and wind. The results of the study which was conducted in Malaysia showed that East windows have more obvious effect on increasing indoor air temperature than West windows for the predominantly hot humid regions. However, in the article (Andersson et al, 1985), the study was carried out for 25 climates in the United States; it was found that in all climates, when the more extensively glazed exposure is oriented to the South; total loads are significantly lower than those in the same buildings oriented to the East or West. North orientation also produces lower total loads than East or West orientations in the Southern two-thirds of the U.S., and roughly equivalent loads in the Northern third. Other researches such as (Bekkouche et al, 2013) studied the orientation effect of a non-air-conditioned buildings on its thermal performance, where the orientation effect has been analysed in terms
of direct solar gain and temperature index for hot-dry climates. Restricted site and orientation optimization in Design were also studied in (Hopefl et al, 2005).

It is well known that thermal interaction between the internal environment of a building and the ambient conditions take place through the building envelop. Principles of good thermal design for hot arid climates require promoting solar heat gain, low window to wall ratio, and tight building envelop. However, for public schools, governmental authorities assign a land plot for the educational facilities, disregarding any considerations of urban context, climate design or efficient orientation, thus increasing energy consumption, decreasing the quality of indoor climate and occupant’s well-being.

In Jordan, due to population growth resulted from forced migrations, the demand on new public schools increased. However, because of limited resources, Jordanian school buildings are not built according to thermal design standards. Therefore, it is essential that the original designs of the new schools should be addressed, according to passive design requirements and adaptations, in order to optimise energy consumption within the most optimum indoor comfort levels possible.

As part of the Jordanian Royal incentive MADRASATI launched in 2008, physical and educational learning support must be provided to empower the existing public school for better education. One of the main concern of the initiative is renovation and refurbishment of existing, under-performing public schools in Jordanian schools. As a result, the engagement in this indicative locally has had a positive impact on Madrasati schools. Student academic performance has improved by 5-8% in 130 schools surveyed, where the Ministry of Education has reported a 10% decrease in truancy at the schools. Moreover, Madrasati currently works in around 500 schools in Jordan, with 174,000 students and 10,700 teachers benefiting. The organization has successfully engaged 650 volunteers from across Jordan.

Consequently, this research will add significant outcomes and recommendations of most financially feasibly solutions for existing schools, according to the initial costs required for the renovation, and the most efficient outcome of occupational energy demand for a high performance indoor quality of classrooms. The importance of studying all orientations, basic and skewed, is viable for renovation of existing schools, nonetheless new public schools in the future.

In a previous research (Al-Arja et al, 2015), the annual total cooling and heating demands per m$^2$ was found for worst, best and average cases as shown in table 1.

**Table 1: results from research (Al-Arja et al, 2015) for N-S and E-W orientations.**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>worst</th>
<th>Best</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWR</td>
<td>50%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Glazing</td>
<td>Single-Low-E</td>
<td>Double</td>
<td></td>
</tr>
<tr>
<td>U-Value</td>
<td>0.45 W/m$^2$.K</td>
<td>0.45 W/m$^2$.K</td>
<td></td>
</tr>
<tr>
<td>Solar control</td>
<td>None</td>
<td>Adjustable</td>
<td></td>
</tr>
<tr>
<td>kWh/m$^2$/year</td>
<td>N-S</td>
<td>40.36</td>
<td>24.36</td>
</tr>
<tr>
<td></td>
<td>E-W</td>
<td>53.5</td>
<td>31.05</td>
</tr>
</tbody>
</table>

**Objectives**

1) To introduce a comparative study between energy consumption optimization for school’s of basic orientations (N-S) and (E-W) and skewed ones (NE-SW) and (NW-SE).
2) To maximize energy savings for heating and cooling in school buildings.
3) To establish energy consumption benchmarks for building sectors, according to orientation optimization.
4) To accumulate a local database including differentiations between building strategies that minimizes energy consumption, comparing Energy Consumption Index in Hot arid regions.
Methodology

Overview

A prototype of Jordanian public schools in Jordan, was chosen to be the case study of this research, also representing the case study in the previous research (Al-Arja et al, 2015). This typical public school design was thermally simulated to achieve the objectives of the study. Classrooms were the main concern in this study, as they consume the highest amount of energy needed for heating and cooling annually. The Design Builder Software (DesignBuilder, 2011) generated school model and main features of the base-case are presented in Table 2.

Table 2: Software (DesignBuilder, 2011) generated school model and main features of the base-case.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Area (m²) / Classroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground floor</td>
<td>30 m²</td>
</tr>
<tr>
<td>First floor</td>
<td>30 m²</td>
</tr>
</tbody>
</table>

Simulated 3D of the base model school main elevation. Total area = 1224 m²

This base model (the prototype model) would be adjusted to specific skewed orientations where classrooms are on both opposite sides of that orientation. The base model should cover the skewed orientations; North East - South West (NE-SW) and North West - South East (NW-SE) orientation options.

To establish the Energy Consumption Index, parametric case buildings were thermally modelled, establishing an annual heating and cooling energy consumption index, in kWh/m², not by price per m², in order to use the resulted values as benchmarks for future studies without being affected by the fluctuating energy prices. Artificial lighting energy demand was not studied in this research.

Parametric study of the base model will be addressed to provide information for comparative dimensions regarding positive and negative, strong and weak parameters for optimum energy consumption. Consequently, the results would provide energy consumption benchmarks for skewed orientation to be added to the findings of previous research (Al-Arja et al, 2015).
**Constant Public School Characteristics, Base model:**

- Building clear interior height = 3m.
- Reinforced non-insulated Slab for the roof, U-value of \(1.163 \text{ W/m}^2\text{.K}\)
- Non-insulated external wall, U-value of \(1.323 \text{ W/m}^2\text{.K}\)
- Clear Single glazed windows
- User occupied 5 days per week from 7:00am to 3:00pm.
- Occupancy density = 0.6 student/m\(^2\), equivalent to 20 students per classroom.
- Cooling temperature set point 24 degrees centigrade.
- Heating temperature set point 18 degrees centigrade.
- Natural ventilation is provided when needed, with no mechanical ventilation available.
- Climate data from the Jordanian Meteorological Department (Climate Data, 2003) was taken for modelling of all cases to represent hot arid climates.
- The building is not surrounded by any building, assuming the nearest possible building is 10 meters away, thus not affecting energy performance.

**Simulation Parameters:**

Table 3 shows the modelling parameters that would be studied in comparison with the basic model and the findings of the previous research (Al-Arja et al, 2015). These simulation parameters were combined to create 54 models for each skewed orientation.

**Skewed Orientations Simulation**

Both North East-South West and North West-South East orientations were simulated for the basic case to establish a benchmark of Energy Consumption Index of conventional construction methods, of public school buildings. Heating and cooling demand as a result of simulation, was standardized for kWh/m\(^2\). All parameters from table 3 will be tested in comparison with the basic case, in order to establish energy performance indicators for different combinations of building envelope adjustments. Furthermore, these results will be compared with the results generated from previous research (Al-Arja et al, 2015) of the original Orientations, North-South and East-West. Annual energy demand per meter square (kWh/m\(^2\)) for worst and best case design options for all orientations, compared with the conventional design, are shown in table 4.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Basic</th>
<th>Change (1)</th>
<th>Change (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window to Wall Ratio (WWR)</td>
<td>35% (normal)</td>
<td>25% (Low)</td>
<td>50% (high)</td>
</tr>
<tr>
<td>Solar Control</td>
<td>None</td>
<td>Horizontal, 50cm deep, non-moving &amp; Vertical fins, 50cm deep, non-moving</td>
<td>Horizontal louvers, 10cm deep, non-moving &amp; Vertical louvers, 10cm deep, non-moving</td>
</tr>
<tr>
<td>Building Envelope Insulation</td>
<td>No insulation, U-value= 1.32 W/m(^2).K</td>
<td>Energy Efficiency Jordanian Code (EEB) (JNBC, 2010) U-value= 0.57 W/m(^2).K</td>
<td>Jordanian Green Building Guide (GBG), (JNBC, 2013) U-value= 0.45 W/m(^2).K</td>
</tr>
<tr>
<td>Glazing Panes</td>
<td>Single, U-value= 6.12 W/m(^2).K</td>
<td>Single with Low-E film, U-value= 4.23 W/m(^2).K</td>
<td>Double, U-value= 2.71 W/m(^2).K</td>
</tr>
</tbody>
</table>
Table 4: Annual energy demand per meter square (kWh/m²), for all orientations (Compared with previous research (Al-Arja et al, 2015) results).

<table>
<thead>
<tr>
<th>Rank</th>
<th>WWR</th>
<th>Glazing</th>
<th>U-Value W/m².K</th>
<th>Solar Control</th>
<th>Energy Demand kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Skewed Orientation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NE-SW</td>
</tr>
<tr>
<td>Heating in Basic</td>
<td>35% (normal)</td>
<td>Single</td>
<td>1.30</td>
<td>None</td>
<td>8.91</td>
</tr>
<tr>
<td>Cooling in Basic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>39.51</td>
</tr>
<tr>
<td>Total in Basic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48.42</td>
</tr>
<tr>
<td>Best for Heating</td>
<td>50% (high)</td>
<td>Double</td>
<td>0.45</td>
<td>None</td>
<td>2.50</td>
</tr>
<tr>
<td>Best for cooling</td>
<td>25% (low)</td>
<td>Single</td>
<td>0.45</td>
<td>Louvers</td>
<td>16.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Double</td>
<td>0.57</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.30</td>
<td>50cm deep</td>
<td>-</td>
</tr>
<tr>
<td>Best for Total Energy</td>
<td>25% (low)</td>
<td>Double</td>
<td>0.45</td>
<td>Louvers</td>
<td>22.77</td>
</tr>
<tr>
<td>Worst for Heating</td>
<td>25% (low)</td>
<td>Single</td>
<td>1.3</td>
<td>Louvers</td>
<td>14.60</td>
</tr>
<tr>
<td>Worst for Cooling</td>
<td>50% (high)</td>
<td>Single</td>
<td>0.45</td>
<td>None</td>
<td>44.98</td>
</tr>
<tr>
<td>Worst for Total Energy</td>
<td>50% (high)</td>
<td>Single</td>
<td>0.45</td>
<td>Low-E</td>
<td>48.94</td>
</tr>
</tbody>
</table>

Results and Comparison Discussions

In this section, an overall comparison will be done for all 8 orientation assumptions, 4 of them were studied in a previous research (Al-Arja et al, 2015) for the N-S and E-W orientated school façades and the other 4 orientations, NE-SW and NW-SE were studied in this research.

A. Window to Wall area Ratio (WWR) and Solar Protection Relationship:

Heating and cooling demand for NE-SW and NW-SE oriented models results are shown in figure 1(a) and 1(b), where WWR and solar protection are compared. Note that all cases for this comparison had single glazed windows, and the building envelope had no insulation. Moreover, table 5 shows the results of this relationship.

It is concluded that for NE-SW and NW-SE orientation, shading bigger windows is more important to lower cooling demand in school buildings. In addition, economical efficiency in regards to initial investment of the solar control device application, and percentage of decrease in cooling demand, is demonstrated for shading larger windows, where cost estimation of the proper solar control can range from 12 to 25 JDS/m. However, this shading element is preferred to be a movable one in order to not effect solar radiation admittance in winter, and heating demands can be decreased.

From tables 6, 7 and 8, it is shown that the E-W orientation has the most negative impact for energy consumption, where in the N-S orientation; adding proper solar protection elements maximises energy savings when compared to other orientations, given the lowest negative impact on heating and the highest positive impact on cooling. However, for the total energy consumption savings, the NW-SE case has the highest value. In addition, the impact of energy savings that solar protection has on high WWR is higher than on low WWR, where savings are increased from (5 to 10) percent for all orientations, excluding the E-W orientation where the impact is the same for both WWR values.
Figure 1: Energy demand for (a) NE-SW and (b) NW-SE oriented models results, comparing WWR with solar protection effects, where all windows are single glazed, and the building envelope is un-insulated.

Table 5: The relationship between WWR and Solar protection

<table>
<thead>
<tr>
<th>Window to Wall Ratio WWR</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% (low)</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td>50% (high)</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

- Effect of solar protection on Heating: ↑ 12-23% ↑ 27% ↑ 10-25% ↑ 30%
- Effect of 50cm deep shading on Cooling compared to no shading: ↓ 47% ↓ 50%
- Effect of Louvers on Cooling compared to 50cm deep shading: ↓ 31% ↓ 31%

Table 6: Percentage of Energy Consumption for all School façade Orientations

<table>
<thead>
<tr>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>70</td>
<td>78</td>
<td>70</td>
</tr>
<tr>
<td>Heating</td>
<td>30</td>
<td>22</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 7: Percentage of Energy Consumption when adding fixed external shading devices for all School façade Orientations

<table>
<thead>
<tr>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating increased by shading</td>
<td>5</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>Cooling decreased by shading</td>
<td>30</td>
<td>15</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 8: Percentage of total Energy decrease when adding shading devices for all School façade Orientations, according to WWR.

<table>
<thead>
<tr>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy consumption decrease- Low WWR</td>
<td>5</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Total energy consumption decrease- High WWR</td>
<td>15</td>
<td>9</td>
<td>25</td>
</tr>
</tbody>
</table>

B. Window to Wall area Ratio (WWR), Solar Control and Building Envelope U-value Relationship, for Heating demand:

Heating demand for NE-SW and NW-SE oriented models results are shown in table 9, figure 2(a) and 2(b), where WWR, Solar Control and U-value are compared. Note that all cases for this comparison had single glazed windows with Low-E film.
It is concluded that for NE-SW and NW-SE orientation, only 0.05m thick polystyrene is enough to apply as an insulation material (cost 3.5 JDs/m$^2$) in Jordan, in order to achieve optimized energy performance, with 0.57 W/m$^2$.K as U-value. On the other hand, applying for a U-value of 0.45 W/m$^2$.K is a more expensive option, when adding 0.07m thick insulation (cost 6 JDs/m$^2$). In addition, it is obvious that a significant increase in heating demand is resulted by adding fixed solar protection, which makes it very important to use movable elements to eliminate the negative effect on heating demand.

From Table 10, it is shown that the impact of insulation in the building envelope verses no-insulation, is almost the same for all orientations, where it has (40 to 59)% positive impact on heating consumption. The highest savings occurred in the E-W orientation, where the lowest savings were achieved in the N-S orientation.

In addition, table 11 shows that when comparing GBG U-value requirements with the EEB U-value requirements, savings don’t exceed 14% of energy consumption use for heating, which is almost the same for all orientations.

However, table 12 shows that when adding 50cm deep horizontal/vertical shading device on all orientations, the highest heating energy increase is noticed in the E-W case, where the N-S orientation has the lowest heating demand potential. This concludes that it is not recommended to shade the East and West facades with fixed 50cm deep vertical shading device; adjustable shading devices should be used instead.

![Figure 2: Heating demand for (a) NE-SW and (b) NW-SE oriented models results, comparing WWR, solar protection and U-values, where all windows are single Low-E glazed.](image_url)

**Note:**
- 25(1) 25% WWR (low), U-Value = 1.31 W/m$^2$.K
- 50(1) 50% WWR (high), U-Value = 1.31 W/m$^2$.K
- 25(2) 25% WWR (low), U-Value = 0.57 W/m$^2$.K
- 50(2) 50% WWR (high), U-Value = 0.57 W/m$^2$.K
- 25(3) 25% WWR (low), U-Value = 0.45 W/m$^2$.K
- 50(3) 50% WWR (high), U-Value = 0.45 W/m$^2$.K

**Table 9: The relationship between WWR, Solar protection & Building Envelope U-value, Heating demand.**

<table>
<thead>
<tr>
<th>Window to Wall Ratio WWR</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of U-value 0.57 W/m$^2$.K on heating compared to U-value 1.31 W/m$^2$.K</td>
<td>$\downarrow$55%</td>
<td>$\downarrow$48%</td>
</tr>
<tr>
<td>Effect of U-value 0.45 W/m$^2$.K on heating compared to U-value 0.75 W/m$^2$.K</td>
<td>$\downarrow$13%</td>
<td>$\downarrow$11%</td>
</tr>
<tr>
<td>Effect of adding 50cm deep solar control on heating for U-value 1.31 W/m$^2$.K</td>
<td>↑13%</td>
<td>↑16%</td>
</tr>
<tr>
<td>Effect of louvers on heating: U-value 1.31 W/m$^2$.K</td>
<td>↑33%</td>
<td>↑39%</td>
</tr>
<tr>
<td>Effect of 50cm deep solar control on heating for U-value 0.57 W/m$^2$.K and 0.45 W/m$^2$.K</td>
<td>↑15%</td>
<td>↑18%</td>
</tr>
<tr>
<td>Effect of louvers on heating for U-value 0.57 W/m$^2$.K and 0.45 W/m$^2$.K</td>
<td>↑49%</td>
<td>↑35%</td>
</tr>
</tbody>
</table>
Table 10: Percentage of heating energy saving when achieving the EEB Code minimum requirement of U-value 0.57 W/m².K compared to un-insulated cases for all School façade Orientations

<table>
<thead>
<tr>
<th></th>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Demand - Low WWR</td>
<td>50</td>
<td>59</td>
<td>55</td>
<td>50</td>
</tr>
<tr>
<td>Heating Demand - High WWR</td>
<td>40</td>
<td>59</td>
<td>48</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 11: Percentage of heating energy saving when achieving the GBG U-value of 0.45 W/m².K compared to the cases with EEB Code minimum U-value 0.57 W/m².K for all School façade Orientations

<table>
<thead>
<tr>
<th></th>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Demand</td>
<td>10</td>
<td>14</td>
<td>13</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 12: Percentage of heating energy increase when adding 50cm Deep Horizontal/Vertical shading for all School façade Orientations

<table>
<thead>
<tr>
<th></th>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-Insulated - Heating Demand - Low WWR</td>
<td>13</td>
<td>20</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Un-Insulated - Heating Demand - High WWR</td>
<td>15</td>
<td>27</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>EEB - Heating Demand - Low WWR</td>
<td>13</td>
<td>30</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>EEB-Insulated - Heating Demand - High WWR</td>
<td>15</td>
<td>43</td>
<td>18</td>
<td>22</td>
</tr>
</tbody>
</table>

C. Window to Wall area Ratio (WWR), Solar Control and Building Envelope U-value Relationship, for Cooling demand:

Cooling demand for NE-SW and NW-SE oriented models results are shown in table 13, and figure 3(a) and 3(b), where WWR, Solar Control and U-value are compared. Note that all cases for this comparison had single glazed windows with Low-E film.

This concludes that it is important to apply shading devices on both SW and SE facades, for high WWRs, especially horizontal louvers, in order to prevent solar radiation admission in hot season, and consequently decrease cooling demands.

Table 14 shows how cooling energy demand increases when complying with the EEB code requirements for all orientations, where the N-S facade has the highest potential increase and the NE-SW orientation has the lowest increase in cooling demand. This indication does NOT eliminate the importance of complying with minimum U-value required by the EEB code for all orientations. On the other hand, table 15 shows that when replacing high WWR with low WWR, cooling demand savings are higher, for all un-shaded orientations. The highest difference in performance between low and high WWR is achieved in the NW-SE orientation, where the NE-SW orientation has the lowest difference in performance. This should not compromise the quality of daylight penetration in classrooms.

![Figure 3](image_url)

Figure 3: Cooling demand for (a) NE-SW and (b) NW-SE oriented models results, comparing WWR, solar protection and U-values, where all windows are single Low-E glazed*.

Note:*
Table 13: The relationship between WWR, Solar protection & Building Envelope U-value, Cooling demand.

<table>
<thead>
<tr>
<th>Window to Wall Ratio WWR</th>
<th>NE-SW 25% (low)</th>
<th>NE-SW 50% (high)</th>
<th>NW-SE 25% (low)</th>
<th>NW-SE 50% (high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of U-value 0.57 W/m².K on cooling compared to U-value 1.31 W/m².K</td>
<td>↑6%</td>
<td>↑9%</td>
<td>↑10%</td>
<td>↑13%</td>
</tr>
<tr>
<td>Effect of adding 50cm deep solar control on cooling for U-value 1.31 W/m².K</td>
<td>↓16</td>
<td>↓21</td>
<td>↓18</td>
<td>↓27</td>
</tr>
<tr>
<td>Effect of adding louvers on cooling for U-value 1.31 W/m².K</td>
<td>↓39</td>
<td>↓45</td>
<td>↓46</td>
<td>↓54</td>
</tr>
</tbody>
</table>

Table 14: Percentage of cooling energy increase when achieving the EEB Code minimum requirement of U-value 0.57 W/m².K compared to un-insulated cases for all School façade Orientations

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Cooling Demand Low WWR</th>
<th>Cooling Demand High WWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-S</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>E-W</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>NE-SW</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>NW-SE</td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 15: Percentage of cooling energy savings when using un-shaded Low WWR instead of un-shaded High WWR for all School façade Orientations

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Cooling Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-S</td>
<td>30</td>
</tr>
<tr>
<td>E-W</td>
<td>32</td>
</tr>
<tr>
<td>NE-SW</td>
<td>25</td>
</tr>
<tr>
<td>NW-SE</td>
<td>33</td>
</tr>
</tbody>
</table>

D. Window Glazing, Solar Control, and Window to Wall Ratio (WWR) Relationship, for heating demand:

Heating demand for NE-SW and NW-SE oriented models results are shown in figure 4(a) and 4(b), where window glazing, Solar control and WWR are compared. Note that all cases for this comparison have an un-insulated building envelope presented by a U-value of 1.31 W/m².K. In addition, Figure 4(c) shows the comparison of savings achieved on heating demand when using different kinds of glazing for windows, in regards to the window area.

It is concluded that for NE-SW and NW-SE it is more feasible and cost affective to use the relatively cheaper single glazed windows with a Low-E film (cost estimated of 25 JDs/m²) than double pane windows (cost estimated of 60 JDs/m²). This is when compared to the amount of heating demand saved when compared to using the conventional type of glazing (single glazed, estimated cost 18 JDs/m²).

Table 16 shows the impact of three glazing types energy usage for both low and high WWR. It is found that single Low–E glazing has the most positive impact when compared with single glazing, in addition to its feasibility regarding cost and market availability, for all orientations.

---

Table 16: Percentage of cooling energy savings when using un-shaded Low WWR instead of un-shaded High WWR for all School façade Orientations

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Cooling Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-S</td>
<td>30</td>
</tr>
<tr>
<td>E-W</td>
<td>32</td>
</tr>
<tr>
<td>NE-SW</td>
<td>25</td>
</tr>
<tr>
<td>NW-SE</td>
<td>33</td>
</tr>
</tbody>
</table>

---

Figure 4: Heating demand for (a) NE-SW and (b) NW-SE oriented models results, comparing window glazing types, Solar control with WWR, where the building envelope has a U-value of 1.31 W/m².K*.

**Note:**

25(SingleClear) 25% WWR (low), windows Single glazed 50(SingleClear) 50% WWR (low), windows Single glazed
25(SingleLow-E) 25% WWR (low), windows Single Low-E glazed 50(SingleLow-E) 50% WWR (low), windows Single Low-E glazed
25(Double) 25% WWR (low), windows Double glazed 50(Double) 50% WWR (low), windows Double glazed
Figure 4 (c): comparison of savings achieved on heating demand when using different kinds of glazing for windows, in regards to the window area, for NE-SW and NW-SE orientations, in percentage.

Table 16: Percentage of savings in heating demand achieved from each glazing type compared to each other for different WWRs, for all School façade Orientations

<table>
<thead>
<tr>
<th>Orientation</th>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving on Heating-Low WWR-single Clear compared to Single Low E</td>
<td>9.1</td>
<td>8.6</td>
<td>8.2</td>
<td>8.8</td>
</tr>
<tr>
<td>Saving on Heating-Low WWR-single Low-E compared to Double Clear</td>
<td>3.2</td>
<td>3.0</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Saving on Heating-high WWR-single Clear compared to Single Low E</td>
<td>14.7</td>
<td>14.7</td>
<td>12.7</td>
<td>14.9</td>
</tr>
<tr>
<td>Saving on Heating-high WWR-single Low-E compared to Double Clear</td>
<td>4.8</td>
<td>5.0</td>
<td>6.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

### E. Window Glazing, Solar Control, and Window to Wall Ratio (WWR) Relationship, for Cooling demand:

Cooling demand for NE-SW and NW-SE oriented models results are shown in figure 5(a) and 5(b), where window glazing, Solar control and WWR are compared. Note that all cases for this comparison have an un-insulated building envelope presented by a U-value of 1.31 W/m².K. Moreover, tables 17 and 18 show the results of this relationship.

In table 19, it is found that when using high WWR instead of low WWR, cooling is increased for all orientations, where the increase is the highest in the E-W orientation and the lowest in the N-S orientation, regardless of shading device availability.

It was concluded that cooling demand is affected mostly by window area and the availability of the solar control elements, regardless of the window glazing and panes.

Table 17: Cooling demand percentage increase when applying a 50% window to wall ratio (high area) instead of 25% window to wall ratio (low area).

<table>
<thead>
<tr>
<th>Effect of solar control</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of no solar control on cooling</td>
<td>↑26</td>
<td>↑28</td>
</tr>
<tr>
<td>Effect of adding 50cm deep solar control on cooling</td>
<td>↑19</td>
<td>↑20</td>
</tr>
<tr>
<td>Effect of adding louvers on cooling</td>
<td>↑16</td>
<td>↑15</td>
</tr>
</tbody>
</table>

Table 18: Comparing the effect of adding solar control to an un-shaded building, on cooling demand.

<table>
<thead>
<tr>
<th>Window to Wall Ratio WWR</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% (low)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of adding 50cm deep solar control on cooling</td>
<td>↓16</td>
<td>↓23</td>
</tr>
<tr>
<td>Effect of adding louvers on cooling</td>
<td>↓39</td>
<td>↓46</td>
</tr>
<tr>
<td>50% (high)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of adding 50cm deep solar control on cooling</td>
<td>↓16</td>
<td>↓25</td>
</tr>
<tr>
<td>Effect of adding louvers on cooling</td>
<td>↓39</td>
<td>↓48</td>
</tr>
</tbody>
</table>
Table 19: Percentage of cooling energy increase using High WWR instead of Low WWR for all Orientations.

<table>
<thead>
<tr>
<th></th>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Shading Device</td>
<td>25</td>
<td>30</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>With 50cm Deep Horizontal/ Vertical Shading Device</td>
<td>15</td>
<td>24</td>
<td>19</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 5: Cooling demand for (a) NE-SW and (b) NW-SE oriented models results, comparing window glazing types, Solar control with WWR, where the building envelope has a U-value of 1.31 W/m².K.

Note:* 25(SingleClear) 25%WWR (low), windows Single glazed 50(SingleClear) 50%WWR (low), windows Single glazed 25(SingleLow-E) 25%WWR (low), windows Single Low-E glazed 50(SingleLow-E) 50%WWR (low), windows Single Low-E glazed 25(Double) 25%WWR (low), windows Double glazed 50(Double) 50%WWR (low), windows Double glazed

F. Adding movable solar protection for energy consumption optimization:

From the results of simulations, it was found that adding fixed solar protection had a positive impact on cooling demand and negative one for heating. However, when adding movable solar protection elements (manual or automated), this impact can be shifted to be positive all year round.

In order to find the optimum energy consumption, all of the cases for NE-SW and NW-SE orientations where examined to find that the building with double pane glazing, 0.45 W/m².K building envelope U-value, no solar protection, and high window area was the optimum building for heating demand.

The results of the optimum case energy consumption in NE-SW and NW-SE orientation are shown in Table 20. This table also shows comparison with N-S and E-W cases studied in the previous research (Al-Arja et al, 2015).

Figures 6(a) and 6(b) show heating, cooling and total energy demand when using movable solar protection elements for the NE-SW and NW-SE with single glazing and low-E film, putting the solar protection in only when cooling is needed, and putting it away when solar radiation admittance is desired.

In order to make this building optimum for cooling demand, movable shading can be added to lower energy consumption. Table 21 shows the decrease in cooling demand when adding movable solar protection for the hot season, for the optimum case.

This concludes that adding movable solar control elements is highly advised for NW-SE oriented cases, for all window areas (high and low WWR), and only recommended for NE-SW oriented cases with low window area ratio not high window area ratio.

Table 22 shows the percentage of energy saving when using adjustable shading devices, where they are on in summer and off in winter. The table shows that the higher the WWR, the higher the saving in cooling and total energy consumption. The highest savings are achieved in the NW-SE orientation and the lowest impact is in the E-W orientation.
Table 20: Optimum case for NE-SW and NW-SE oriented building cases, compared with N-S and E-W oriented building cases.

<table>
<thead>
<tr>
<th>Case name</th>
<th>Heating kWh/m²/year</th>
<th>Cooling kWh/m²/year</th>
<th>Total kWh/m²/year</th>
<th>Heating Saving %</th>
<th>Cooling Saving %</th>
<th>Total Saving %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum NE-SW</td>
<td>2.50</td>
<td>20.92</td>
<td>23.42</td>
<td>71.94</td>
<td>47.05</td>
<td>51.63</td>
</tr>
<tr>
<td>Optimum NW-SE</td>
<td>2.96</td>
<td>20.81</td>
<td>23.77</td>
<td>69.70</td>
<td>47.49</td>
<td>51.88</td>
</tr>
<tr>
<td>Optimum N-S</td>
<td>4.08</td>
<td>22.28</td>
<td>26.36</td>
<td>63.80</td>
<td>32.59</td>
<td>40.54</td>
</tr>
<tr>
<td>Optimum E-W</td>
<td>1.80</td>
<td>37.51</td>
<td>39.31</td>
<td>76.03</td>
<td>10.80</td>
<td>20.68</td>
</tr>
</tbody>
</table>

Table 21: decrease in cooling demand when adding movable solar control for the hot season, for optimum case.

<table>
<thead>
<tr>
<th>Window to Wall Ratio WWR</th>
<th>NE-SW Effect</th>
<th>NW-SE Effect</th>
<th>NE-SW Effect</th>
<th>NW-SE Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% (low)</td>
<td>↓39</td>
<td>↓12</td>
<td>↓39</td>
<td>↓48</td>
</tr>
<tr>
<td>50% (high)</td>
<td>↓30</td>
<td>↓10</td>
<td>↓29</td>
<td>↓40</td>
</tr>
</tbody>
</table>

Table 22: Percentage of energy saving- adding adjustable shading in summer for all façade Orientations

<table>
<thead>
<tr>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Demand- High WWR</td>
<td>35</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>Cooling Demand- Low WWR</td>
<td>27</td>
<td>17</td>
<td>39</td>
</tr>
<tr>
<td>Total Consumption- High WWR</td>
<td>27</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Total Consumption- Low WWR</td>
<td>19</td>
<td>10</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 6: Energy demand for (a) NE-SW and (b) NW-SE oriented models results, comparing the effect of movable solar control availability with no shading, for single Low-E, high and low window areas.

Research Conclusions and Recommendations:

According to the analysis of the results and findings of the research, the following points present the recommendations and conclusions:

- For schools sector in hot arid climate generally, and in Jordan specifically, the Energy Consumption Index is concluded from the research, and refers to energy consumption/m² of area, annually, for both heating and cooling demand. The following table shows the detailed values:

<table>
<thead>
<tr>
<th>Lowest Energy consumption (Best case scenario) kWh/m²/year</th>
<th>N-S</th>
<th>E-W</th>
<th>NE-SW</th>
<th>NW-SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest Energy consumption (Worst case scenario) kWh/m²/year</td>
<td>40.36</td>
<td>53.5</td>
<td>48.94</td>
<td>52.08</td>
</tr>
</tbody>
</table>

The average consumption value could be used as an Energy Consumption Index, and a benchmark, for future energy evaluation studies, in the educational sector in Jordan.
Upon energy costs in Jordan for 2017, the following values show savings for optimum case scenarios of all orientations if compared with the average energy consumption value, and increase in energy consumption cost when compared with the worst case scenarios. The values are represented in JDs/m$^2$/year, and as total cost increase or decrease for the school building evaluated in this research with the total area of 1224 m$^2$.

<table>
<thead>
<tr>
<th>Facades Orientation</th>
<th>Worst compared to average (additional consumption)</th>
<th>Optimum compared to average (Saving in energy consumption)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>JDs/m$^2$/year Total for School JDs/year</td>
<td>JDs/m$^2$/year Total for School JDs/year</td>
</tr>
<tr>
<td>N-S</td>
<td>1.254</td>
<td>1.146</td>
</tr>
<tr>
<td></td>
<td>1534.9</td>
<td>1402.7</td>
</tr>
<tr>
<td>E-W</td>
<td>1.725</td>
<td>1.643</td>
</tr>
<tr>
<td></td>
<td>2111.4</td>
<td>2011.0</td>
</tr>
<tr>
<td>NE-SW</td>
<td>1.941</td>
<td>1.887</td>
</tr>
<tr>
<td></td>
<td>2375.9</td>
<td>2309.7</td>
</tr>
<tr>
<td>NW-SE</td>
<td>2.112</td>
<td>2.135</td>
</tr>
<tr>
<td></td>
<td>2585.1</td>
<td>2613.2</td>
</tr>
</tbody>
</table>

- Always provide shading for high WWR in all facade orientations of school building in Jordan, and consequently the hot arid climate.
- It is more economically feasible to use single pane glazing with Low-E film for all orientations, compared to single and double glazed windows, when linked with both the initial cost of the glazing and the energy savings attained.
- As recommended in the previous research, the minimum U-value of 0.57 W/m$^2$.K for the building envelope, required by the Energy Efficient Building (EEB) Code of Jordan should be complied, not more or less than this value, when linked with both the initial cost of the insulation material and the energy savings attained.
- As recommended in the previous research, incentive schemes should be developed for the use of movable solar control elements, in order to overcome their high initial cost, (estimated to range from 15 to 30 JDs/m$^2$).

References


Sunlight Directing System: The Effect of Surface Topology on Daylighting Performance

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Abstract: Sunlight directing systems (SDS) are used in façade design to improve visual comfort, avoid direct sunlight and reduce energy consumption. A successful application of the SDS is based on how to control light bounces in accordance with distinctive characteristics of SDS. In addition to the factor of cross-section design which, in particular, can largely affect how light is directed.

Many studies in the literature have been conducted for SDS to increase daylight availability. Most of these studies have focused on design characteristics of a simple SDS, but the effect of surface topology of SDS units on daylight have been rarely examined. Correspondingly, this paper aims to examine the characteristic of surface topology of SDS (i.e. flat, curved) to increasing daylight availability with minimal direct sunlight penetration for deep-floor spaces. The study also integrated different SDS parameters of; angle of rotation, depth and spacing between SDS units within the tested parameters.

The study used a mid-size southern office space located in hot climate of Cairo, Egypt. Research method incorporated parametric modelling tool ‘Grasshopper’ linked with daylight simulation engine ‘RADIANCE’ through DIVA daylight simulation tool to carry out daylight simulations.

The results demonstrated that the distance between SDS units is the first influential parameter mostly improves daylight performance with a minimal direct sunlight. While the depth and the rotation angle come in the second place. Finally, the surface topology has the weakest influence.

Keywords: Daylight, façade, sunlight-directing system, RADIANCE

Introduction

Sunlight directing systems (SDS) are commonly used for facade systems to enhance daylight performance. It can prevent discomfort glare, rid of direct solar heat again and therefore improve the visual and thermal performances in built spaces. In addition, there is energy saving potentials expected from installing light directing systems (Mayhoub, 2015). In general, light directing techniques have an advantage over other regular shading techniques as it doesn’t reflect the light but re-direct it at a different angle to strength low daylighting levels, specifically at deep floor areas (Knaack, 2007);(El Sheikh, 2011).

Basically, sunlight directing systems work in different ways; there are horizontal, vertical and combined horizontal and vertical elements. The horizontal elements prevent solar radiation striking a south facade at a steep angle from reaching the interior spaces. While vertical elements prevent solar radiation striking east or west facades at a shallow angle from penetrating the interior (Szokolay, 2014);(Reinhart, 2014).

Initially, SDS controls light reflectivity thus increases deep daylit zones using indirect light. The performance is further enhanced when minimal or no direct sunlight is received. Nevertheless, if such devices are not precisely designed, it may admit more sun rays than needed or result in poor daylit spaces. Besides, when designing SDS the climatic conditions have to be considered carefully as for instance; the locations with predominantly cloudy skies require different strategies from those with mostly clear skies (Aksamija, 2013);(Gadelhak, 2013). Moreover, the climatic conditions change in relation to time of day and season.
Therefore, the effects of facade elements (e.g. shade, reflection, redirection of light) also change, depending on the respective solar altitude angle (Herzog, 2004).

Many studies investigated the performance of the SDS in different climates. The SDS parameters were examined to enhance daylighting performance and to reduce energy consumption. The controllable parameters of different sunlight directing systems (e.g. louvers, light shelves and overhangs) were widely examined. SDS rotation angle was specifically examined as the main parameter that controls light reflection, in addition to the depth and number of SDS units.

For a louvers-system, Detta examined louver parameters including angle of rotation, depth and distance between louvers with respect to annual solar gains and energy performance in a southern façade located in Italy. The study recommended using louver system with certain parameters to effectively reduce total energy consumption (Datta, 2001). González also investigated a façade design based on louver system using an optimization approach to enhance daylighting performance by controlling same parameters for a northern façade located in Sydney (González, 2015). As for or hot climate contexts, Wagdy used a parametric approach where a combination of facade parameters and flat louver system (i.e. window to wall ratio, louvers count, louvers tilt angle, screen depth ratio, and screen reflectivity) were parametrically controlled and computed for daylighting analysis using a southern oriented space located in Cairo, Egypt. It was found that louvers count has no remarkable influence when combined with different screen parameters. Moreover, louvers depth ratios were proven to inversely related to daylighting performance, and it contributed in blocking direct sunlight. In essence, the findings from Wagdy’s study showed some limitations in terms of the overall performance of each parameter separately since some parameters were found to restrain the influence of the others (Wagdy, 2015). In general, the previous research found that controlling louver parameters can lead to substantial improvements in daylight performance. Furthermore, Olsen developed a light directing system using parametric design approach for three climate zones (Los Angeles, Mexico City and Anchorage). The study tested louver’s length for heat mitigating and daylight enhancing (Olsen, 2013).

As for light shelves systems; Lim explored different numbers and depths of light shelves for a façade system to improve daylight performance for all orientations in Singapore. The study measured daylight performance on a real scale model and proved that using light shelves can effectively control and distribute daylight in inner space (Lim, 2014). Gadelhak found that controlling sun breakers parameters; angle of rotation, depth and number can successfully enhance façade performance for a southern façade located in Cairo (Gadelhak, 2013). Mayhoub tested façade parameters including light shelves and perforated skin for a southern façade located in Cairo, Egypt. The study defined façade parameters that optimized the thermal performance together with daylighting availability (Mayhoub, 2015). Moreover, a combination of light shelf and solar screen configurations was investigated by Sabry et al. to enhance the daylight distribution. The study found that adding light shelves showed an improvement in the overall performance (Sabry and others 2012). Another study conducted by Eltaweel used a control strategy for sunlight directing system with a cut-off angle that follows sun movement. The system was applied in the upper window zone of a south-oriented façade in Cairo. The distance between slats was assumed fixed and the rotation angle was independently set to follow sun movement for fixed targets on the ceiling. The system effectively enhanced daylight coverage in deep floor area, although it showed some weakness with low sun angle (Eltaweel, 2017b, Eltaweel, 2017a).
Researchers around this area have been evolved further to include the dynamic movement of sun directing systems. For example, El Sheikh tested the effectiveness of light deflection in a dynamic skin layer installed in a south façade in terms of daylighting performance, using independent tilt angles of rotation (El Sheikh, 2011). The selected parameters of the sunlight directing units were originally based on (McGuire, 2005) study that examined the effect of venetian blind’s reflected angle in accordance with ceiling illuminance. The study of El Sheikh demonstrated that using independent tilt angles for skin panels has the potential to achieve better daylight performance.

In conclusion, the literature review showed that controlling SDS parameters have been widely examined for visual and energy performances. Generally, there is a consensus on SDS to enhance daylight and energy performance. The literature revealed that SDS parameters of distance, depth and rotation angle can substantially influence the resulted predictions and can lead to tangible improvements in daylighting and energy performances. However, it should be noted that most of these parameters were driven mainly for a flat shape of SDS.

Since the main idea of SDS is based on how light is reflected and redirected, surface topology of SDS is a crucial factor that may affect how light is controlled and accordingly how daylight is distributed. For example, a diffused topology of SDS surface was found to distribute light differently compared to a specular flat surface (Lee. H., 2016). Thus, there is a potential to further improve daylight performance through controlling surface topology of SDS together with other controllable parameters. However, as reviewed above, most of the aforementioned studies cited in the literature have focused mostly on the performance of simple flat SDS considering various controllable parameters of rotation, distance, etc., but the effect of surface topology with respect to all other parameters remains unstudied. Correspondingly, this paper aims to investigate SDS parameters combined with different cross-section configurations to increase the delighted zone with minimal direct sunlight penetration.

**Methodology**

In order to define the impact of the shape (cross-section) of SDS combined with other parameters (includes depth of the units, rotation angle on the units and spacing between SDS units) on daylighting performance, the methodology incorporated a parametric model that controls SDS parameters/cross-section using parametric design and simulation tools. These are Rhinoceros 5.0, Grasshopper plugin for Rhinoceros (McNeel, 2010) and DIVA 4.0 simulation tool (Solemma, 2014).

The simulations were carried out in two stages. The first stage focused on evaluating the performance of flat cross section of SDS in order to establish a baseline case for the comparison and give an insight about the parameters that largely affect daylight performance. Whereas the second stage combined the curved (one side and two sides convex shapes) cross section and analysed it for daylight performance. Model parameters, simulation method and SDS parameters are explained in more detail in the following sections.

**Sunlight directing system (SDS) parameters**

A south oriented office space located in Cairo, Egypt, was modelled using grasshopper software. Space dimension and characteristics are based on a shoebox model (reference model) proposed by Reinhart (Reinhart, 2014, Reinhart, 2013) with typical dimensions of 3.6m (width), 8.2m (depth) and 2.8m (height) as shown in Figure 1. The space features a fully glazed façade with no outside obstructions. The analysis sensor points were set in a grid of
60x60 cm and at 80cm height for light calculation, in agree with the requirements of Illuminating Engineering Society (IES) (IESNAI, 2012). The selected materials and proposed reflectance were set as shown in Table 1. The space is assumed occupied from 8am to 6pm. This occupancy model used as it represents a generic model recommended for detailed performance analysis of an individual daylit spaces (IESNAI, 2012).

![Spatial dimension of the office space](image)

**Figure 1 Spatial dimension of the office space**

<table>
<thead>
<tr>
<th>Space parameters</th>
<th>Area</th>
<th>29.52 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor level</td>
<td>ground</td>
<td></td>
</tr>
</tbody>
</table>

| Internal surface materials | Walls      | Reflectance 50% |
|                           | Ceiling    | Reflectance 80% |
|                           | Floor      | Reflectance 20% |
|                           | Outside ground | Reflectance 20% |
|                           | Glazing    | Double-pane clear (Tvis80%) |
|                           | SDS units  | Reflectance 30% |

The study includes SDS parameters of depth, spacing between units and rotation angle. In stage one, SDS system was analysed for all variables with flat SDS, as shown in Figure 2. Depth values were set to be 20, 25, 30, 35, 40, 45 and 50cm. The vertical distance between units along the façade was set to be 20, 30, 40, 50 and 60 cm. The selected rotation angles defined as follows: 0, 10, 15, 20, 25, 30, 35, 40, and 45 degrees. As explained previously, the aim of stage one is to establish a base line case that represents the parameters which lead to best daylight performance obtained with the flat SDS.

In stage two, these parameters were tested for the curved shapes of SDS. The study used two topologies of curved SDS that are commonly used. The first is a one-side (upper side) convex shape. The second topology is a two-side convex shape (ellipse cross-section). In addition, the tangent angle values of the curvature of the both cases are 15, 30 and 45 degrees.

Some parameters of SDS (e.g. rotation angle, depth) were kept and varied while testing the performance of curved SDS, whereas the distance was set fixed based on the initial results of stage one as will be explained later in the results section. The parameters of stage one and two are illustrated in Figure 2-4.
Daylighting evaluation criteria

To evaluate daylighting performance, Climate-Based Daylight Modelling (CBDM) metrics are used. It predicts luminous quantities (i.e. illuminance and/or luminance) using realistic sun and actual sky conditions that are derived from data in standardised climate files (Reinhart, 2012). It uses metrics such as Daylight autonomy (DA), which allows the user to calculate the percentage of a given time frame when a minimum illuminance reference level on a work plane is met by daylight (Bartenbach, 2014). It is also adopted by LEED 4 in the recent released version which uses two metrics for Daylight Autonomy evaluation; Spatial Daylight Autonomy
(sDA) and Annual Sun Exposure (ASE) metrics. Spatial Daylight Autonomy (sDA\textsubscript{300/50%}) reports the percentage of the floor area in which the illuminance levels reach 300 lux for at least 50% during the occupied hours (8 am–6 pm) throughout the year. On the other hand, ASE reports the direct light beam received in indoor work plan throughout the year. ASE measures the percentage of the floor area in which the illuminance levels reaches 1000 lux for at least 250 hours during the occupied hours (8 am–6 pm) throughout the year (IESNAI, 2012);(USGBC, 2013). Both indicators are used in this study to provide a clear picture of the daylighting performance within the tested space.

**Simulation workflow**

The simulation process linked the parametric shoebox model featured with SDS with DIVA daylighting simulation tool through grasshopper software. The DIVA plug-in for Rhinoceros/Grasshopper software is used to calculate daylight estimates using the RADIANCE/ Daysim engine (Jakubiec, 2011). RADIANCE simulates the physical behaviour of light in a volumetric, three-dimensional model which should most accurately represent reality (Ward, 1994), and it has been validated in many studies (Reinhart, 2011);(Ng, 2001);(Reinhart, 2001);(Ibarra, 2011).

The annual daylight analysis was based on the daylight coefficient method proposed by (Reinhart, 2000) that considers 148 sources for diffuse calculation corresponding to the 145 Tregenza sky divisions (Tregenza, 1987), plus 3 divisions that include contributions to the indoor illuminance due to external ground reflections. While for the direct component, 63 direct solar positions are considered.

A matrix of the given parameters was created for SDS to be simulated for each stage. Due to the multiplicity of the variables examined in this study, a parametric workflow, proposed by Wagdy (Wagdy, 2013), was used to control modelling and simulation process without switching between modelling software (i.e. grasshopper) and daylight simulation engine (i.e. RADIANCE). The proposed simulation workflow combined different parameters of SDS via a cross reference model that matches each item of the first variable list (SDS topology) with all the items of the second (distance), third (depth) and fourth (rotation angle) lists. The workflow also allows the results from each simulation run to be automatically written and ordered externally in an excel sheet. Figure 5 shows the simulation workflow adopted in this study.

![Figure 5 The proposed methodology linked the parametric modelling tool (grasshopper) with daylighting simulation engine (DIVA).](image-url)
Finally, RADIANCE setting for lighting calculations was set at 4 ambient bounces as it was statistically proven to produce reliable results compared to high precision setting (6-ab) with shorter simulation time (Abdelwahab et al., 2017).

Results

Stage 1 (flat cross section)

As explained, the aim of this stage is firstly to establish a baseline case on which other types of SDS (i.e. curved) will be compared against. Secondly, to define the parameters that largely enhance/decline daylight performance so these parameters can be considered in the next stage. Considering all various parameters, this gives in total 350 cases.

The results generally showed that reducing the depth of SDS increased daylight coverage in terms of sDA%. The increment in daylight estimates is becoming evident when using large distance between SDS units and/or low angle of rotation. See Figure 6 and 8. However, in some cases, this caused in receiving more direct light (i.e. ASE) as shown in Figure 7 and 9.

For instance, small depth of SDS (e.g. 20cm) increased the percentage of sDA% but it allows for large amount of direct light to reach the work plane. This may possibly lead in turn to receive glare since high illuminance levels have a direct correlation with the probability of glare occurrence (Mardaljevic, 2012, Nezamdoost, 2017). Results are improved gradually when larger depths of SDS, such as 40, 45 and 50 cm, were used. Nevertheless, increasing the distance between SDS units (i.e. 50, 60 cm) declines daylighting quality again, as the increased distance between SDS units allows for more direct light to reach the indoor space. This requires, in turn, to increase the depth of SDS units. As can be seen in Figure 6, daylight availability may be varied from 90% to 20% sDA based on the in-between distance and depth of SDS units.

In brief, the results showed an inverse relationship between the depth and the number of SDS units. The reduction of SDS unit’s number (larger distance between SDS units) requires either to increase the depth, and the reduction of louver’s depth is required either to increase the number of SDS units (smaller distance between SDS units).

With all parameters considered, the best performance in terms of high sDA% together with low ASE% often occurs when the distance reaches 40 cm between SDS units, by which the daylit cases that reached sDA of 50% or more and, at the same time, ASE less than 10% are about 60% of total tested cases. As for the depth parameter, value of 45cm revealed in more successful cases (46% of total tested cases) obtained same criteria of sDA% and ASE%.

As for rotation angle, the results showed a decline in daylight coverage (i.e. sDA%) when the inclination of rotation angle increases. This consequently caused a reduction in the percentages of ASE%. See Figure 8 and Figure 9. Among different proposed rotation angles, rotation angles of 15 and 20 degree mostly enhanced daylight coverage with lower direct sunlight penetration (43% of the cases). In general, it should be noted that the results are largely dependent on the other parameters of depth and distance between SDS units.

In summary, among different tested parameters of flat SDS, the distance parameter was found the most influencing factor as it revealed in a pronounced improvement in daylight performance in the first place. While the depth and rotation angle of SDS come in the second and third place.
Figure 6 sDA% for different depths and distances (values represent the average taken from all rotation angles)

Figure 7 ASE% for different depths and distances (values represent the average taken from all rotation angles)

Figure 8 sDA% for different rotation angles and distances (values represent the average taken from all depths)

Figure 9 ASE% for different rotation angles and distances (values represent the average taken from all depths)
Stage 2 (curved cross-section)

In stage two; the cross section of SDS was examined and compared against the flat shape. Since the study seeks further performance enhancement, it will take the best scenario in stage one and carry out more investigations using the additional parameter of SDS shape. In the previous stage, distance of 40cm between SDS units was the point where most of cases reached sDA 50% or higher and met the requirements of ASE (less than 10%) at the same time for the majority of the cases. Therefore, this distance was adopted in this stage as a fixed parameter for the distance between SDS units. Whereas other variables of depth and angle of rotation were kept. Additionally, the curved shape of SDS units was examined with tangent angles of 15, 30 and 45 degrees for all the cases. This generates 210 cases in total for one side and two-sides convex shapes separately.

In order to compare the results of the curved shape against the flat shape, the study used the boxplot to show the median, minimum and maximum sDA% and ASE%. The results of all flat SDS cases are compared with the results of the one side convex SDS (Figure 10) and the two-side convex SDS (Figure 11) for all suggested curvature angles.

The boxplots generally showed that the curved shapes of SDS units decrease sDA% values compared to the flat shape. The analysis show that the median of sDA% gradually declined when the tangent angle of curvature shape increases. The effect is more evident when using two-sides convex shape of SDS compared to the one-side convex SDS. In terms of direct light calculations, the results of median ASE% were mostly consistent for all several
types of SDS. These results can be justified since the total height of the SDS geometry is generally larger in case of curved cross-section compared to the flat geometry. This may contribute in providing more shade and blocking large amount of light that penetrate the façade. Thus, sDA% values were less in case of curved shape compared to flat cross section. In addition, the multiplicity of surfaces that the curved SDS consists of may partially reflect the light back to the outside and, accordingly, reduce indoor daylight coverage.

The previous results suggest that the curved topology of SDS can slightly decline daylight distribution compared to the flat topology although the results in terms of direct light almost remain consistent.

Limitations

It should be noticed that the resulted performances are mainly dependent on the climatic conditions, orientation and spatial characteristics which the simulation carried out for.

Conclusion

This paper aims at exploring different parameters of sunlight directing system in terms of daylight performance in the context of hot regions under Cairo climate. Among different parameters, vertical distance, depth, rotation angle and the topology of SDS geometry (i.e. cross section) were examined for both daylight coverage using the benchmark of sDA%, and direct solar penetration using the benchmark of ASE%. The following conclusions can be drawn from this study:

- There is an inverse relationship between some parameters of SDS such as depth and count of SDS units. The reduction of SDS unit’s number requires either to increase the depth, and the reduction of louver’s depth is required either to increase the number of SDS units.
- The inclination of rotation angle decreases daylight distribution inside the space compared to non-rotated SDS. But, on the other hand, it can successfully block direct sunlight in case daylight requirements sufficiently met. Accordingly, this may contribute in reducing the probability of glare occurrence. The rotation angle therefore should be installed to control direct light penetration in accordance with the prevailing conditions and other SDS parameters.
- As for the topology of SDS units (cross-section), the curved SDS slightly declined daylight coverage since the analysis revealed lower values of sDA% compared to the flat shape, but the effect in terms of direct sunlight (ASE) remains almost constant.
- Finally, among all tested parameters, the vertical distance between SDS units showed a pronounce influence on enhancing daylight performance with minimal direct sunlight. The factors of depth, rotation angle come in the second and third places respectively. Whereas the cross-section slightly influences daylight performance compared to other parameters.

It is suggested that more parameters, such as surface reflectivity and different compositions for SDS cross-section (V or W shapes), could be explored in future studies. Also, more performance aspects can be potentially examined for thermal comfort and glare occurrence.

References


Upgrading the Energy Performance of Existing Middle-Class Suburban Residential Buildings in the Gulf Region

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Abstract: The economic, political, and cultural developments in the GCC states of the past four decades have led to a rapid and unsustainable urban development. Due to the low price of energy, for a long time there has not been an economic necessity to implement energy saving measures for residential buildings. Reinforced concrete structures and uninsulated walls made of concrete hollow blocks are omnipresent. Yet, the energy consumption of buildings in the Gulf region is unnecessarily high. Since the dependence upon oil is intended to be reduced, reforms are necessary. In contrast to many other countries, sustainable solutions have not yet adequately been implemented. Many essential actions for energy savings are missing. Until today, there is still too little awareness for energy efficiency in buildings. The suburban residential buildings contain a large number of deficits. The building regulations are not sufficiently supporting energy efficient construction methods. Effective incentives are missing. Retrofit strategies are urgently needed. The transition to more sustainable solutions is overdue. Fundamental transformations are necessary. Within this paper, typical suburban residential buildings will be analysed regarding their energy performance. Based on this analysis, a series of improvement options will be identified, evaluated, and prioritised according to their efficiency and economic feasibility (e.g. optimisation of building envelope, reduction of thermal bridges, installation of external shading, thermal massing, and solar energy generation). Thereafter, implementation strategies will be developed to demonstrate how the energy efficiency of existing residential buildings can be effectively increased.

Keywords: Energy efficiency, retrofitting, green building, sustainable design

Introduction – There is an urgent necessity for improving the energy performance of suburban residential buildings in the Gulf region.

This paper aims to point out feasible and cost effective solutions of how the existing suburban residential buildings can be transformed into significantly more energy efficient buildings. With the research guidelines, there is the intention to contribute to the creation of more awareness, and knowledge for all professionals, who are involved in the Gulf countries’ construction and planning sectors. Here, climate adaptation strategies play a major role.

While the problem at hand impacts all professional stakeholders in determining the best strategy to take existing housing infrastructure and transform these buildings into more fully energy efficient, green properties, the concern here is focused upon collaboration with private owners. In doing so, the focus remains transfer of knowledge to the private owner as they increase awareness of this issue. While the issue is not new, the level of awareness can build to increase more environmentally responsible choices to create pathways to energy efficiency in every Gulf region home. The concept of low energy
architecture must be redeveloped in terms of offering innovative solutions as practical to the everyday use.

Furthermore, St Clair (2009) supports how the region can adopt traditional design elements of the Gulf as basis for more energy efficient design, moving forward to further design innovation and seeking to make the Gulf region a model for other nations facing similar challenges. Both Mujeebu and Alshamrani (2016) and St Clair (2009) see potential in the region to become a leader to prompt other nations to adapt similar marrying for traditional housing features with ‘green’ functionality. The better use of space toward creating, sustaining, and renewing the energy lifecycle also supports increased socioeconomic gains for the region’s people. Outsiders might see such innovation taking place at the private ownership level, become inspired, and seek to promote such elements in his or her own homes as evolving the lifestyle to focus on green values (St Clair, 2009).

**Analysis of existing suburban residential buildings in the Gulf region regarding their energy efficiency**

Part of considering future changes to existing properties to bring them up to speed and compliance toward renewable standards also means identifying weak areas of the existing housing. Harnessing the power of renewable and green concepts also means focusing on how cooling strategies create massive impacts to the use of air condition units and increase the loss of energy by creating thermal bridge situations, also points to simple preventative steps that can be taken to reduce these behaviours (Friess and Rakhshan, 2017).

The first focus remains to examine how building plots are considered for the suburban site and how buildings may differ moving from nation to nation within the Gulf States. Below Figure 1 illustrates the differences in plot sizes from Muscat, Dubai, and Riad where the use of space varies greatly. For instance, in Oman, the common plot size is either 20m x 20m = 400m² or 20m x 30m = 600m². In the UAE example, common plot sizes in general are varying between 15m-30m x 20m-45m = 300 m² - 1350m². Whereas in Saudi Arabia, the common plot sizes run between 12m-30m x 20m-30m = 240m²-900m². The demand of energy has not been carefully considered when the plot sizes and building typology have been determined.

![Muscat (GPS 23.3908 58.0652), Dubai (GPS 25.1549 55.2847), Riad (GPS 24.3438 46.3724)](image)

Figure 1. Typical suburban residential clusters in Muscat, Dubai and Riad, with plot sizes 20m x 30m with single and twin villa type (Muscat), Dubai example with plot size 25m x 45m and Riad example with plot size 20m x 25m (images are in same scale).
Furthermore, one must consider common features inherent within existing suburban residential planning and building where these plan reflect specific local standards to remain compliant to local building regulations. There are legal restrictions that may not correlate to lifestyle provisions (St Clair, 2009). Regulations warrant how each structure is built with limits toward height, having one to three floors, how the structure holds up the perimeter wall (mandatory), freestanding building units (due to set back rules by law), and exposure to sun (unfavourable building orientation). Due to the buildings’ set back regulations, the plots’ walled private outdoor spaces have “corridor-like” forms which are difficult to use, except for the front side which in most cases is used for parking (von Richthofen, 2016). Figure 2 represents how the villa type does not fit with the climate throughout the Gulf region. The choice for the villa type structures with its different styles of clusters has not been made with consideration of sustainable design. For building compliance, there is the concern for how regulations can be upheld or modified.

![Figure 2. Typical cluster with different residential villa types (Example: Oman).](image)

Especially the ratio between building surface and building volume of the villa type is very unfavorable in regard to an efficient use of energy. Compared to the traditional houses, the detached home has a larger surface area or building envelope which significantly increases the burden for cooling. The one floor villa structure in general creates the highest deficient.

The existing structures suffer from poor planning in regard to sun exposure. Both Von Richthofen (2016) and Yang et al. (2014) consider the issue of proper placement of the building to be strategic for comfort and maximizing what the climate has to offer in terms of seeking renewable sources such as solar options. Proper and minimized exposure to the sun while also creating green spaces supports a shift in focus to improve the homeowners’ living conditions (St Clair, 2009). Seeking to maximise potential shade is not seen in villa style structures and the choice of building materials are not used with maintaining energy efficiency either. Examples are foundation plate, walls, and roof lacking proper insulation where such choices can reduce burden to cooling the structure. Furthermore, Figures 3 and 4 display how choices of building materials impact the building’s disability to conserve energy. Hollow concrete blocks do not much help the situation. Choosing to plaster inside and outside directly on the hollow concrete blocks without use of insulation also contributes to the building’s disability to maintain temperatures and thus high demand of cooling loads.
The building analysis especially takes into account how windows contribute to energy use. The window to wall ratio in some cases is much too high, which results in a highly increased demand for cooling energy due to the fact that the heat transfer through windows is much higher than through walls. The highest heat gains come from windows that are exposed to direct sunlight. The orientation of windows often has not been developed according to a minimised exposure to direct sunlight. Figure 5 illustrates a typical single glazed window with an uninsulated aluminium frame. These types of windows are containing major thermal leaks. Also the quality of the window’s glazing plays an essential role in regard to the building’s energy efficiency. Even though the windows of many villas are equipped with a solar reflectance coating, in most cases their glazing consists only of a single pane of glass. And the window’s frames usually are not insulated, there is no thermal division between inner and outer part of the frame. Furthermore the window to wall connections contain severe thermal bridges. All these points lead to immense thermal losses caused by the windows, especially during the hotter summer months. Figure 5 illustrates a typical single glazed window and brings attention to the importance of the window within the energy conservation strategy.
Existing residential buildings have other flaws contributing to energy loss which are found in the ventilation systems of the kitchen and bathrooms. Vent fans in most cases are directly inserted into the windows allowing direct air flow and heat exchange between interior and exterior space. De Wolf et al. (2017) have examined the deficits of suburban Middle Eastern residential neighborhoods with the support of simulation software with a special focus on operational energy.

Further flaws point back to insulation and ineffective sealing of connections between doors and windows with the building all of which increase thermal bridging. Leaks and use of several exterior doors within the home (some according to custom and gender needs) also increase the thermal loss.

The building envelope is not tight. When cool air cannot be trapped and leaks out, when windows or doors do not close off well, then there are huge energy losses. Based on the examples in Muscat, Diener et al. (2015) consider how the villa style does not work to meet the needs of the environment. Such findings point to the design as flawed where: Solid walls with u-values of ca. 1.6 to 2.2 W/m²K; Roofs ca. 1.0 to 2.0 W/m²K; Ground floor plate ca. 1.0 to 2.0 W/m²K; with single glazed windows and doors, also uninsulated frames ca. 3.0 to 4.0 W/m²K; Entrance doors ca. 3.0 to 5.0 W/m²K.

The villa design also does not plan for external use of shade. Windows are continually exposed to the sunlight. The building design often appears to be random (Diener et al., 2015). In most cases, the solar reflectance index neither plays a role for the choice of the façade colour nor for the façade material and surface structure.

The same can be said for the ventilation system and design can focus upon how windows can become smart and rotate horizontally to promote better air circulation and energy distribution. Windows should be replaced to meet increased functionality to support the natural flow within the home. This makes a more happy homeowner as well. St Clair (2009) contends that much like choosing the window, focusing upon how to maximise the energy efficient potential of the existing home also points to the choices the homeowner makes. To ‘green’ the home, this means attention to integrate sustainable plants for environmental or local conditions. Today much of the plants used in the villa design is for decoration only. Plants do often not serve another use whereas they could be providing shade, a breeze, and fruit to the homeowner (Kibert, 2016).

Water is delivered and stored in tanks on the roof. Sewage is also collected in a tank and disposed of with a service for each home. Frankly, this is complex and wasteful. Furthermore, to reduce water use, homes must be fitted with fixtures and devices to control the use as water consumption is highest in the Gulf. St Clair (2009) sees simple changes in thinking can support better consumption practices, together with integrated systems across the board that supports legal changes to water consumption.

Identification of various retrofit measures to save operational energy and reduce CO2 emission of existing suburban residential buildings

Below in Table 1, the author devised a ‘toolbox’ to explore the different retrofit intervention options for seeking to further emphasise the need for energy efficiency. One can build upon existing bones of the structure to make the home more efficient but also realising what can be learned from these enhancements in terms of innovation for residential design of future homes.
### Table 1. Toolbox of various retrofit intervention types.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Common Standard</th>
<th>Improvement Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reducing sun exposure</td>
<td>The sun exposure has not been considered. Facades with its windows, roofs (with water tanks and technical installations) are not covered / protected in order to reduce solar overheating.</td>
<td>Exposed areas of the façade and roof can be partially shaded with trees or other elements, which cover the façades and roof from the sun. Especially all sun exposed windows must be shaded. Water tanks and technical installations could also be covered.</td>
</tr>
<tr>
<td>2 Insulating the ground plate</td>
<td>There is no insulation.</td>
<td>There is insulation.</td>
</tr>
<tr>
<td>3 Insulating the walls</td>
<td>There is no insulation.</td>
<td>There is insulation.</td>
</tr>
<tr>
<td>4 Insulating the roof</td>
<td>There is no insulation.</td>
<td>There is insulation.</td>
</tr>
<tr>
<td>5 Adapting window to wall ratio</td>
<td>Some buildings have very large glazed areas, and there is too high an amount of windows in regards to the ideal daylight illumination of the interior spaces.</td>
<td>Only in the mentioned specific cases with too large of an amount of windows, a retrofit solution might be to reduce the glazed areas, and replace some of them with wall area in order to reduce thermal losses and cooling loads.</td>
</tr>
<tr>
<td>6 Renewal of window frames</td>
<td>There are uninsulated aluminium frames.</td>
<td>Operable window frames with turn and tilt function, thermally separated and insulated, should be installed.</td>
</tr>
<tr>
<td>7 Renewal of window glazing</td>
<td>There is single glazing.</td>
<td>There should be double or triple glazing used, with highly improved U-Values and G-Values.</td>
</tr>
<tr>
<td>8 Optimised connection window to wall</td>
<td>Window to wall connections generally are not tight and provide severe thermal leaks.</td>
<td>There should be airtight sealing of connections.</td>
</tr>
<tr>
<td>9 Renewal of doors to exterior</td>
<td>Uninsulated doors, doorframe to wall connections are generally not tight with severe thermal leaks.</td>
<td>Refurbishment with insulated doors, airtight doorframes and airtight wall connections should be installed.</td>
</tr>
<tr>
<td>10 Closing of ventilation openings kitchen and bathrooms</td>
<td>Kitchen and bathroom vent fans are often integrated into kitchen windows with open areas between inside and outside. This design creates severe thermal bridges.</td>
<td>New kitchen and bathroom ventilations should be retrofitted with products, which are airtight and thermal bridge free.</td>
</tr>
<tr>
<td>11 Installation of external shading</td>
<td>This is rarely applied.</td>
<td>All sun exposed windows are to be protected 100% from direct sunlight.</td>
</tr>
<tr>
<td>12 Improving albedo / exterior surfaces / solar reflectance index SRI</td>
<td>Exterior surfaces of most buildings are bright with already a good solar reflectance applied.</td>
<td>Buildings, or building parts with lower SRI are to be coated with bright colours, and provided with more smooth surfaces, glare needs to be controlled.</td>
</tr>
<tr>
<td>13 Improving daylight use</td>
<td>Many spaces are illuminated with electrical energy. The potential of natural light often is not fully used. In some cases some parts of a building have too much natural daylight.</td>
<td>User awareness to save electrical energy to be established in order to use natural light, and in some cases reduction of glazed area to reduce cooling demands.</td>
</tr>
<tr>
<td>14 Establishing natural ventilation</td>
<td>Windows often are not operable for natural ventilation. User awareness to apply natural ventilation not yet established on broad scale.</td>
<td>Operable windows, cross ventilation, natural ventilation systems should be installed, user awareness created</td>
</tr>
<tr>
<td>15 Integration of green spaces</td>
<td>Most buildings and plots only have very little green elements, and not green roofs.</td>
<td>Green spaces can be integrated on multi levels. Such green provide: Trees for shading, façade green to reduce sun exposure, green roofs as insulation, agriculture for food production etc. All green space contributes to a better microclimate, household water can be recycled for irrigation of the green</td>
</tr>
<tr>
<td>16 Establishing night cooling with thermal massing</td>
<td>This is not applied on a broad scale, even though there are excellent climatic conditions for more than six months in a year.</td>
<td>Adequate sustainable materials can be integrated or added to the existing walls to provide a thermal mass: Clay plaster, and adobe brick elements, etc.</td>
</tr>
</tbody>
</table>
Optimizing
Reducing water
Controlling/reducing use of air conditioners / AC’s
In most households, water is not reused or recycled at all.
Water is reused to be established.
Reduced electric light use
Motion sensors, lighting fixtures to significantly save electric light, and maximisation for the use of natural daylight.

| 18 | Optimizing material properties | The main building material is concrete. | There should be use of local materials. Reusable, degradable, recyclable materials are to be added, reinforced concrete is to be avoided. |
| 19 | Introducing energy generation | This is not applied on broad scale, even though there are excellent conditions for the entire year. | Photovoltaics, solar warm water heating, and small wind generators to be integrated in the households. |
| 20 | Controlling/reducing use of air conditioners / AC’s | AC’s, as individual split units are installed in each room to be cooled. Noise disturbs, especially in the bedrooms. Use of AC’s often not sufficiently controlled according to users’ needs. | Increased controlled use of AC’s according to users’ needs. Natural cooling by natural ventilation and thermal massing can significantly reduce the need of AC’s (as well as many of the other mentioned techniques). |
| 21 | Solar warm water heating | Electrical boilers are used for warm water heating. | Solar water heating can significantly reduce the electrical energy required. |
| 22 | Water reuse | In most households, water is not reused or recycled at all. | Water reuse and water recycling techniques are implemented to decrease waste. |
| 23 | Reducing water consumption | There is insufficient awareness by the users. Water consumption per capita is among the highest worldwide. | Water saving fixtures to be installed (e.g., low-flow fixtures, and high-efficiency toilets) and reuse to be established. |
| 24 | Reduced electric light use | Due to low energy prices, there is little awareness by the users to install energy saving devices. | |

There are many actions that can take place to form sustainable enhancements to energy and water preservation that also focuses on human behaviour and desire to perform changes to commit to different ways to cut energy use and costs. St Clair (2009) comments once the homeowner understands how such changes promote a less expensive energy and water truck bill, they will see the benefit of making such changes a best practice. With practice, making better choices to retrofit the building will better the community and the whole of the Gulf region.

First for new buildings or existing buildings that can be extended, there is seeking better orientation of the structure. This practice keeps in mind how the seasons are interactive with the house where north and south facades are more desired. Here once the position is determined, insulation remains key to success of the retrofit. Insulating the ground plate proves to benefit the whole of the structure and support better energy flow throughout the house. Insulation of walls also provides the structure with better ways to maintain thermal variances. Wall insulation allows the building conserve the cool during the summer and literally breathe during the winter with a cross flow of energy. So at winter nights when it is cool, the building would be ventilated and during the day, being cool from night, the building would not need to work as hard to maintain cool in the heat (Al-Maamary et al., 2017). Furthermore, without doing the same to the roof, the cool is lost directly through the roof. Insulation allows the cool to be trapped and cover the greater area to reduce the burden in warmer months.

One cannot ignore insulation and sealing of the windows and doors as these promote huge gaps in connections throughout the inside and outside of the building. Dependent upon how the orientation exposes the building to sun light, the amount of windows in many cases should be fewer than in the current villa design. Windows should be renewed with double or triple glazing and functional movement for ventilation. They also should be equipped with appropriate exterior shading to cover the window at appropriate times to reduce solar overheating. Doors must be tested for the amount of air flow when closed (blower door test) because this will serve to point to where gaps in the connection exist for better alignment.
With redesign of living space also comes the need to increase natural ventilation dependent upon the season and how to promote a cross breeze according to window use and position of the building to begin with. With such conversation, the ways in which the homeowner uses electricity also evolves to reduce the light use of electric sources because the natural light from the window often is enough. Furthermore, natural ‘green’ elements also increase the cooling and improves the microclimate around the building by specific placement and selection of plants for more than decorative use. Use of plants can also block sun exposure during hotter months but also support better use of night cooling effects that allow the structure to store energy.

Keeping in mind the existing structure may have limitations to how its position supports better control of thermal properties, future smart homes of the area will learn to optimise the materials to support the higher degree of thermal distribution needed to maintain the need for outside energy supplies. In other words, the new home should be able to sustain itself based on enhanced redesign and use of better materials (Czechowski et al., 2014).

The reinvented home of the Gulf region will consider energy generation through renewable sources such as solar and wind as well as, seeking thermal supply by simply control of maintaining structural elements like windows and doors. Energy generation is important to the future of any home but especially one located in an extreme environment. The home must work with the environment to sustain itself. With this in mind, reduction and control of internal systems like AC’s and mechanical ventilation make sense to contribute to reducing the homes fingerprint upon the environment. Use of solar technology like the smart roof (Elon Musk) contributes to heating and cooling but also seeking a solution promoting cleaner forms of energy different from before. Use of potable water and recycled water through a garden, oasis type feature centrally located in the most used areas of the home also serve to build a comfort to the home and allows the homeowner to benefit for less use of water services. This reduces footprint by eliminating the service delivery use of petrol and further allows for human behaviour in the lifestyle to adjust to reuse of local resources (at home) instead of convenient and over consumption.

**Evaluation and priorization of the (suggested) improvement measures**

While there are many improvement measures discussed in detail above, Figure 6 also effectively illustrates how each step increases the reduction of energy use in an impactful way that allows the homeowner to benefit from making these changes as investments in a more efficient home. What remains interesting in terms of creating a movement toward changing human behaviour also suggests that one choice leads to another where education and knowledge are key to creating the need for this shift of lifestyle. In fact, the new and improved house will be designed with such trends in mind where further enhancements built upon these ideologies where innovation increases the options. Such excitement also increases the amount of participation and movement away from designs that do not work well for the region, i.e. the villa design.
Conclusion: implementation strategies

After comparing and evaluating the identified improvement options as illustrated in the previous chapter, it was possible to create an order of effectiveness with recommendations which retrofit measures are most suitable for the homeowners. Even though many decision making factors depend on the individual situation, there can be a priority list with general recommendations of how existing buildings can be transformed with the best cost effectiveness. Looking at Figure 6 above, one can pinpoint strategies the region can implement for transformative change to the way the consumer views energy use.

In addition, the following strategies would also strongly contribute towards more energy efficient suburban neighbourhoods in the Gulf region: Adapting the building regulations in regard to better green building standards (e.g. rising the baseline U-value specification), enforcing better the building regulations, rising awareness by better informing and educating the population about sustainable behaviour, creating financial incentives for the homeowners to invest in sustainable retrofit measures with climate responsive building techniques.
Further studies

Further and future studies will focus upon creating building simulations that can model the best case scenarios for the building of new homes in the region. Such software based building simulations will use supportive data as evidence toward promoting specific strategies in home building such as better insulation and positioning of windows, doors, and the most commonly used family areas. With such simulations, the optimal retrofit intervention measures can be identified in relation of cost to energy savings. Further studies will also focus on the creation of multifamily homes instead of single family dwellings to promote more compact building units for a better energy use, to reduce the expense to the homeowner and to reduce the burden to the region in terms of services and infrastructure.

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Light Shelf System in Energy Conservation to enhance Daylight Performance on Overcast Condition in Buildings

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Abstract: Daylighting represents an important factor in human's life and well-being. It increases the production of the hormone and causes more productivity in space. In recent studies, advanced and innovative daylighting systems could improve the illumination level in interior space by using innovative materials. And they could enhance healthy indoor environment by using physical laws of reflection, absorption and refraction to illuminate working plane level in the proper rooms. The current study aims at improving window position in buildings according to daylighting requirements, designing recommendations to enhance internally daylighting performance, and reducing energy consumption by using artificial lighting during daytime, and enhancing human health and poor perception of ambient nature by using visual perception sense. In the same context, this paper aims to use light shelf system (which are reflective surfaces that reflects direct sun lights inside the interior space to enhance natural lighting inside the place) with innovative materials and achieve daylighting requirements. Determining daylight availability and annual daylight glare probability (DGP%) in winter are used in simulation analysis to measure daylighting distribution in bed room area. The main target and outcome of the paper is creating a simulation and testing the light shelf system using Diva plug-in for Rhinoceros, to figure out the best material, geometry, location, and inclination of lighting shelves to reach the maximum performance design of the shelf itself and with the building envelope.

Keywords: Light shelf system, Daylighting, Visual comfort, Daylight Glare Probability, Innovative materials

Introduction

Many problems in daylighting arise from its special nature, because the window has to perform its function not only of admitting light, but also of providing the view outside of nature scene and the desired visual contact with outside world (Hopkinson, 1996; Collins, 1975). The importance of daylight comes after food because the body consumes 1/4 energy to perceive indoor environment in poor lighting conditions (Hopkinson, 1996). The human body is nourished directly by the stimulation of sunlight or is nourished indirectly by eating foods, drinking fluids, or breathing air which has been vitalized by the sun's light energy. This light energy does not only affect our physiological activities and moods, but recently it has been shown to produce an effect in the body which is similar to that produced by physical training and its resultant improvement in physical fitness (Liberman, 1990).

Eye is like a socket. It opens and closes to visual performance to improve human health. The same case is found in buildings, whose windows are also like a socket to building’s spaces which provide them with the light so that people can see interior spaces and provide good ventilation for the human health requirements. The relation between window position and visual effects in the interior is described by Vitruvius (Hopkinson, 1996). Windows are strongly favored in work places to provide daylight, view out, ventilation, privacy, thermal protection, and improve mood. Environmental surroundings
are monitored through windows during different times of the day. Windows are decorative and are as a functional tool in building’s facade in architecture profession. They are considered a main important element in designing process as they reduce energy consumption. Windows will produce an improvement in mood depending on priority of occupants which enhances human health for physiologically and psychologically (Boyce et al, 2003). Moreover, they determine how our houses can help us to be liveability and healthy by distributing pattern of light and dark. We use windows as tools to control privacy, glare and temperature, as well as light exposures and view.

Daylighting availability of natural light is determined by latitude of building’s location in Sinai as a case study, but in overcast sky condition in winter season is low illuminated value. We need to increase daylight in quantity, quality and well distribution pattern in the rear area of the room by using advanced daylighting systems (Illumination Engineering Society [IES] about task 21) (Phillips, 2000).

Light Shelf is an effective system to reflect bright light from zenith area (upper sky dome) to darkness area of test room in residential area. Light shelf system can be used also in different sky conditions but with another specifications and parameters that those used in upper sky dome condition. Also, it analyses daylighting performance’s (DIVA for RHINO) simulation and evaluates the output results by Excel sheet to achieve optimum daylighting performance.

**PROBLEM IDENTIFICATION**

In this study, daylighting techniques are used such as light shelf and some parameters are changed (width, structured materials, material’s color, cross section, position, shape and thickness) relating to room depth and its benefits.

All calculations which are assumed to improve window design according to minimum area of window area (15%) in the external wall area (WWR) (Permanent committee to code’s preparations, 2006). Moreover, the window is designed in hot humid region, in addition to requirements of windows for cooling and heating loads to reduce the electrical consumption as well.

**RESEARCH OBJECTIVES**

This paper aims at:

- Using advanced daylighting systems and technology of daylighting tools to improve indoor daylighting.
- Maximizing and optimizing light shelf system with different positions and materials to reflect highlight rays to the rear area.
- Describing the light shelf’s system design, as well as, experimental assessment of the performance of the illuminance to have quality and quantity illuminated value in work plane.
- Achieving visual comfort according to the international ratio of daylight’s distribution indoor (1:0.30:0.10) in near window area, middle area and the rear area in the back of room’s space.
- Approving the positive effective light shelf system in daylighting performance and environmentally friendly design in residential building’s design.
HYPOTHESIS

This study, in residential area, assumes that daylight in two room spaces (4.0 X 4.0) m² and (4.0 X 5.0) m² have very low distributed light levels in the Centre window and in the aspect left positioned. And the overcast sky condition in 21 Dec 2016, at 10:00 AM, has very low distributed light according to El Arish weather. All variants of light shelf parameters such as Materials, Color reflection factor, Width, Thickness and Height from window's lintel are applied by using computational analysis.

METHODOLOGY AND RESEARCH TOOLS:

Empirically, in this study, daylighting simulation programs (Grasshopper model + Rhinoceros Generative modeler + DIVA for Rhino) are used to measure the light shelf system and its factors in bed room area (4.0x4.0) m² and (4.0X5.0) m² through weather file’s input and location of El Arish Figure 1. By using light shelf system, we can achieve the optimum benefit of daylighting distribution to comfort visual curve with some changes to physical and architectural properties (rendered and visualization) Figure 2.

Through all previous studies which were applied to reference room, we gain 432 cases about left and center window's position, and then we choose the best cases that shown visualization and pattern distribution of illuminated space recommendations. The architectural window is responsible for entering the theme of daylight that is changed in quality and quantity. The codes of different illuminated engineering societies (IES) and living room /bed room in a home are 100-300 lux (taken from code for interior lighting, CIBSE UK, 1994) as a recommendation in daylight design (Permanent committee to code’s preparations, 2006) (phillips, 2000).
To improve visual indoor space, there are six visual principles of light which facilitate the visual dialogue between light and space such as; illuminance, luminance, color and temperature, height, density and direction/distribution that are empirical by nature. But these quantifiable measures embody only a portion of their working potential together (Descottes et al, 2011).

Illuminance plays a critical role in our emotional response and feelings to a space; we fear of dark spaces and safety, reassurance of light spaces and faith. Also, it describes quantity of light or energy that is administrated at appropriate levels, and it provides us with visibility, safety, and emotional satisfaction (Descottes et al, 2011). According to daylighting regulation’s, intensity reduces into deep area of the room, which is out of window area (Hadidy, 2012). The human’s eye adapted daylight to visual comfort in a space by following the proportion (1: 0.3: 0.1). So, the daylight is 100% in near of window, 30% in the middle and 10% at the end area of space (which didn’t cause a glare in quality) (Hopkinson, 1996).

Table 1. The main parameter of bed room space and window opening, input data for modeling and simulation.

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Residential area</th>
<th>Parameters of room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room components</td>
<td>Reflectance factor(p)</td>
<td></td>
</tr>
<tr>
<td>Floor</td>
<td>15%</td>
<td>Plaster, dark tile</td>
</tr>
<tr>
<td>Walls</td>
<td>50%</td>
<td>White matte paint</td>
</tr>
<tr>
<td>Ceiling</td>
<td>70%</td>
<td>White finish paint</td>
</tr>
<tr>
<td>Door</td>
<td>35%</td>
<td>Brown color related to (p)</td>
</tr>
<tr>
<td>Window</td>
<td>15% Internal Reflectance</td>
<td>White frame + clear glass</td>
</tr>
<tr>
<td>Position of window</td>
<td>In the center and aspect Left of wall</td>
<td></td>
</tr>
<tr>
<td>Floor level</td>
<td>Zero level (ground floor)</td>
<td></td>
</tr>
<tr>
<td>Room dimensions</td>
<td>Room (1) 4.0 x 4.0 x 3.0 m³ Room (2) 4.0 x 5.0 x 3.0 m³</td>
<td></td>
</tr>
<tr>
<td>Window orientation</td>
<td>North (all directions)</td>
<td></td>
</tr>
<tr>
<td>Window to wall ratio (WWR)</td>
<td>15% (1.80m2)</td>
<td></td>
</tr>
<tr>
<td>Width of window</td>
<td>1.00 m</td>
<td></td>
</tr>
<tr>
<td>Sill height</td>
<td>0.90 m</td>
<td></td>
</tr>
<tr>
<td>Lintel height</td>
<td>2.70 m</td>
<td></td>
</tr>
<tr>
<td>Glazing</td>
<td>Single clear glass 6mm</td>
<td></td>
</tr>
<tr>
<td>Visual transmittance VT</td>
<td>88%</td>
<td></td>
</tr>
<tr>
<td>U-Value (W/m2 K)</td>
<td>6.121</td>
<td></td>
</tr>
<tr>
<td>Light shelf system</td>
<td>Variable Width - depth - Height - Materials - Cross section Out external wall positions</td>
<td></td>
</tr>
<tr>
<td>Work plane height (m)</td>
<td>0.60 m</td>
<td></td>
</tr>
<tr>
<td>Daylight grid spacing calculations</td>
<td>0.50 m</td>
<td></td>
</tr>
<tr>
<td>Sky condition</td>
<td>Overcast sky</td>
<td></td>
</tr>
<tr>
<td>Time of calculation</td>
<td>Winter 10:00Am (21/12/2016)</td>
<td></td>
</tr>
</tbody>
</table>

**Lighting Level**

Lighting levels can identify the ease of visibility. Efficiency of visual tasks is in direct proportion with the foot-candle level and the light which is scattered in the space. Most of us have a vertical vision cut-off which is about 45° degrees above the horizon. If the light fixture is beyond this angle, there will be no visual discomfort. The question of glare is complicated. Glossy papers increase glare. On the other hand, the same light, that is directional and produces glare, is the light that is necessary to understand three dimensional forms.
Outdoor light levels may vary from sky brightness about 30,000 or more Lux to alight level in the shadow of a tree about 500 Lux or less, approximately. The Impact of Lighting on Health for long time has definitely deleterious effects to human health. The individual’s thinking is impaired; his visual perception becomes disturbed, and his brain pattern changes. It is predictable that a work ambiance in different areas is identified through different amounts of light. Light is used to establish a sense of place, possibility of visual relief and contrast which would provide a more human enjoyable place to spend one’s working hours, and reduce incidence of psychosomatic headaches and fatigue, or driving a person out of his self-control.

High light levels are disturbing to people with albinism to people with color blindness, and to people with exotropia, making the person effectively blind until lowered light levels once again permit the pupil to enlarge. Low light levels hinder the vision of older people whose pupils become smaller in old age, giving better depth of field but requiring lighter. They are also disturbing to people who dark cannot adapt and to people with other developing forms of cataracts. Inadequate lighting is harmful to the eyes because they cannot find their way into the ophthalmologists’ nosology. Once we have determined where and how much light is needed further energy savings can result (Youssef, 2015). All parameters of daylighting calculations have been written in below shape from Grasshopper & Diva for Rhino Simulation Figure 4 (computer program) and base to follow methodology Figure 5 and to get results Figure 6.
Figure 5. The main parameter for Material component and the DIVA Daylight component to run a simulation to interface of design process to get a result of daylight simulation to center window position.

**Daylight Glare Probability (DGP%)**

Recently, Daylight Glare Probability is the metrics of glare, but there are at least seven glare indexes such as VCP, UGR, BGI, CGI, DGR, DGI and DGP. These algorithms are Unintuitive, complex, don't often agree with each other and work unequal accuracy for electric and daylight sources (Marilyne et al, 2009). Analytical imperceptible Glare at Fish-Eye camera's view for a sitting positioned at middle distance on the room Figure 7. Glare considers an enemy and dilemma of lighting designer, which a vital issue for building's occupants due to visual discomfort and user acceptance of luminous indoor environment. CIE is following recommendations for acceptable range (CIE, 1995), Comfort zone: (Imperceptible<10 - Just perceptible :13 - Perceptible:16 - Just acceptable :19), discomfort zone :( unacceptable:19 - Just uncomfortable :25 - uncomfortable:>28(Perkins et al, 2013). Wienold, who produced DGP values by using a modified version of Daysim program by temporal map and put a principle could be applicable to the potion of space in which one perceives glare for computing glare (Marilyne et al, 2009), as shown on the next equation.

\[
\text{DGP}=5.87 \times 10^{-5} E_v + 9.81 \times 10^{-2} \log \{ 1+\sum_j \frac{L_s(j)\omega_j^2}{E_v^{1.87} P_j^2} \} +0.16
\]

where \( E_v \) is the vertical illumination at the eye, \( L_s \) is luminance of glare source, \( \omega_s \) the solid angle of the source and \( P \) is the position index of the source.
Illuminance value and daylighting distributions:

A - Illuminance levels distribution in indoor room space of aspect left window position to room (1).

B - Illuminance levels distribution in indoor room space of center window position to room (1).

C - Illuminance levels distribution in indoor room space of aspect left window position to room (2).

D - Illuminance levels distribution in indoor room space of a center window position to room (2).

Figure 6. Shown daylight analysis - daylight illuminance maps in work plane at 0.60 m height from floor in bed room plan, there are cases defined and monitored in table 2.
Figure 7. Analytical rendering graphics with Daylight Glare Probability of camera at the middle room from the window.

**Rendering and visualization:**

Daylighting design combines art and science, and its internal images tend to bluish rendering in overcast sky. A visual trick is used to catch entered person to bed room by nameplate by small colors, according to Danish research "A film about light", architecture and health" (Volf, 2014) Figure 8.

Figure 8. Rendered views of light illuminance distribution  A- Equinox in 12:00 Pm B- winter solstice, which is a film about light, architecture and health.

Daylight is an ideal light to view and cover the complete color spectrum and see objects with natural color. For example, Louis khan design “Kimball Art Museum” is designed by natural light to show their manifested objects. Color evokes personal emotional reactions, which are highly individual and needs special treatment to enhance daylight by the internally reflected components and the requirements of the brightness pattern of visual field (Hopkinson, 1996).
Figure 9. Rendering graphics by camera settings at the middle distance of the room at north direction (winter)

The Research Results

In this stage, the evaluation of light shelf system results, which is extracted by DIVA simulation, to achieve optimum case, to improve and to enhance daylight performance Figure 9 and visual comfort in the bed room is used according to variable parameters, to research tools and assessments.
Table 2. Shown the results of best cases using light shelf system and its parameters by Excel assessment

<table>
<thead>
<tr>
<th>Case NO.</th>
<th>Position of window</th>
<th>Light shelf material</th>
<th>Light shelf position angle</th>
<th>Light shelf position from lintel distance</th>
<th>Light shelf position from lintel</th>
<th>Light shelf width</th>
<th>Light shelf thickness</th>
<th>Light shelf cross section</th>
<th>Day light values</th>
<th>Delight Ratio</th>
<th>DGP%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case1</td>
<td>*</td>
<td>White concrete</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1388</td>
<td>405</td>
<td>98</td>
</tr>
<tr>
<td>Case2</td>
<td>*</td>
<td>Prismatic panel</td>
<td>Upward+30</td>
<td>0.2</td>
<td>0.65</td>
<td>0.02</td>
<td>*</td>
<td>1158</td>
<td>397</td>
<td>90</td>
<td>1:0.31:0.10</td>
</tr>
<tr>
<td>Case3</td>
<td>*</td>
<td>Aluminum sheet</td>
<td>Upward+30</td>
<td>0.2</td>
<td>0.45</td>
<td>0.02</td>
<td>*</td>
<td>1264</td>
<td>385</td>
<td>108</td>
<td>1:0.30:0.18</td>
</tr>
<tr>
<td>Case4</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Upward+30</td>
<td>0.2</td>
<td>0.45</td>
<td>0.10</td>
<td>*</td>
<td>976</td>
<td>299</td>
<td>93</td>
<td>1:0.31:0.10</td>
</tr>
<tr>
<td>Case5</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Horizontal 0°</td>
<td>0.4</td>
<td>0.65</td>
<td>0.02</td>
<td>*</td>
<td>927</td>
<td>327</td>
<td>94</td>
<td>1:0.35:0.10</td>
</tr>
<tr>
<td>Case6</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Upward+30</td>
<td>0.4</td>
<td>0.45</td>
<td>0.02</td>
<td>*</td>
<td>1057</td>
<td>368</td>
<td>105</td>
<td>1:0.35:0.10</td>
</tr>
<tr>
<td>Case7</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Horizontal 0°</td>
<td>0.80</td>
<td>0.65</td>
<td>0.10</td>
<td>*</td>
<td>680</td>
<td>217</td>
<td>51</td>
<td>1:0.32:0.08</td>
</tr>
<tr>
<td>Case8</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Horizontal 0°</td>
<td>0.80</td>
<td>0.65</td>
<td>0.02</td>
<td>*</td>
<td>598</td>
<td>221</td>
<td>49</td>
<td>1:0.37:0.08</td>
</tr>
<tr>
<td>Case9</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Horizontal 0°</td>
<td>0.80</td>
<td>0.65</td>
<td>0.02</td>
<td>*</td>
<td>725</td>
<td>236</td>
<td>53</td>
<td>1:0.33:0.07</td>
</tr>
<tr>
<td>Case10</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Horizontal 0°</td>
<td>0.80</td>
<td>0.45</td>
<td>0.10</td>
<td>*</td>
<td>677</td>
<td>201</td>
<td>53</td>
<td>1:0.30:0.08</td>
</tr>
<tr>
<td>Case11</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Upward+30</td>
<td>0.80</td>
<td>0.65</td>
<td>0.02</td>
<td>*</td>
<td>308</td>
<td>239</td>
<td>57</td>
<td>1:0.30:0.07</td>
</tr>
<tr>
<td>Case12</td>
<td>*</td>
<td>Horizontal 0°</td>
<td>Upward+30</td>
<td>0.60</td>
<td>0.65</td>
<td>0.02</td>
<td>*</td>
<td>890</td>
<td>246</td>
<td>62</td>
<td>1:0.28:0.07</td>
</tr>
</tbody>
</table>
The Research Conclusion

Natural light is very important factor in human life and in the improvement of his health, eye, skin, brain and mental processes. So, the paper is designed to improve daylight in bedroom in residential area. Computational simulation helps us to evaluate and choose the best position to light shelf system as a simple strategy to enhance daylight requirements and performance. The vision of good colors and ambient elements are affected by the daylight quantity and quality in internal space, as shown in Table 3.

- Daylighting is important in human life and well-being in environmentally healthy indoor spaces.
- The architecture of light is expressed in buildings through windows, one oriented to the sun and the other one is oriented to interior living.
- Window design with variable positions in external wall has been a various solution of daylighting systems to enhance daylight performance.
- Improving window position in buildings according to daylight requirements, and suggest recommendations to enhance internally daylight performance, reduce energy consumption, and improve human health and perception of ambient nature by using visual perception sense.
- The ability to know the best position of vertical window at minimum area (WWR%) with suitable light shelf system by using computer simulation assessment (DIVA plug-in for Rhinoceros program) in order to improve daylighting performance in Table 3.
- The best solutions of bedroom area (4.0x4.0) m² according to test performance simulation from 432 cases by using sheet excel evaluation are the left window position, prismatic light shelf material, put Upward+30° position, fix at 0.20 m form lintel, oval cross section's light shelf, and 0.65 m width (case 2) Table 2.
- When the color of the painted room is changed, the reflectance factor is affected. So, the designer should choose suitable light shelf systems.
- Lighting designers are responsible for completing studies on how light will interact and distribute within a given space. These calculations ensure that illuminated levels will be sufficient for visual comfort and are not-damaging to the objects and the materials in the space.
- Lighting designer has seen architectural spaces with his artistic attitude through the experience of scientific attitude, methodology of lighting specifications and good rendered image of space.
- The design process consists of a team work, and a collaboration between different specialties.
- Co-operation between architects in different professions is important to know the software of simulation's programs and the updated knowledge of market's software's.
- Light shelf has two cross sections, the first section is rectangular and the second section is oval /curved surface. There are three types of material input to simulation program (white concrete, prismatic panels, and Aluminum sheet) with various thicknesses to improve daylight performance. So, we can choose the suitable materials according to these types.
• Light shelf is an influential factor to increase the internal reflected components, especially in the rear area at the room and to decrease the lights in near area of the window.
• Light shelf near lintel height windows reflects daylights to ceiling surface then to the rear area of back wall such as .20m more than .80m.
• The designer had three choices to select a material of light shelf according to his requirements of design process and technologies of daylight systems which are permitted to use.

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Assessment of Thermal Behaviour and Energy Consumption of Small Mosques in Hot-arid Climate of Najran City, KSA

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Abstract: In the hot-arid region of Saudi Arabia, buildings need air-conditioning systems to provide a satisfactory level of thermal comfort. Mosque buildings are unique in their function and pattern of operation, thereby requiring a careful design to ensure optimal thermal and energy performance. The objective of this study is to investigate the internal thermal behaviour and energy use of small popular mosques located in the hot-arid climate of Najran City in the Kingdom of Saudi Arabia. The research uses several methods, including selecting a case study of a small mosque, carrying out continuous environmental monitoring using data logging equipment, and collecting annual electric energy consumption and evaluating number of worshippers during the typical five prayers per day. Results indicate the occurrence of energy waste. Thus, thermal comfort is not achieved due to inappropriate building envelope design coupled with improper operation. This study recommends the consideration of passive design strategies in the early design stage and the assurance of a systematic operation schedule for energy use, which can lead to remarkable energy saving without compromising thermal comfort.

Keywords: Energy Efficiency, Thermal Performance, Mosques, Hot-Arid Climate, Saudi Arabia.

Introduction

Mosques represent a place of great importance and unique function where Muslims can come daily together for five intermittent prayer periods with a duration between 45 and 60 min each. These prayers prescribed five times daily: 1) Fajr "the dawn prayer", 2) Dhuhr "the noon prayer", 3) Asr "the afternoon prayer", 4) Maghrib "the sunset prayer", and 5) Isha'a "the night prayer". Thus, a mosque should be designed properly to provide privacy, comfort and calm in the worship area so that worshippers can leave with a feeling of tranquillity and peace. Approximately 3.6 million mosques exist around the world as of 2014, which translates to around 500 Muslims for every mosque. Moreover, with a 1.3% growth per year, the number of mosques around the world is expected to reach 3.85 million by 2019 (Deloitte & (M.E.), 2015).

During the last decade, an approach towards the design of eco-friendly mosques was formulated by regional governments. For example, 90,000 mosques across Saudi Arabia will be made eco-friendly by utilising solar and other renewable sources of energy (Fawaz, 2014). These green mosques are estimated to reduce electricity consumption by approximately 40% and decrease their water use and carbon emissions by 30%–40% (Al-Tamimi, 2017). Morocco has launched an ambitious ‘Energy Efficiency in Mosques’ programme to provide solar power to all mosques in the kingdom; the first-phase deadline is set for 2019, and 600 mosques are set for a green makeover by March 2019 (GIZ, 2014). Jordan is working on making its mosques energy efficient; 400 mosques currently generate their electricity needs via solar energy, whereas 2,000 are expected to be fully operating on renewable energy in two years (Nergaard, 2017).

Buildings in the Kingdom of Saudi Arabia (KSA), including mosques, account for approximately 80% of the total electric energy use in the country for the year 2011 (Al-Tamimi,
Air-conditioning systems represent 70% of the total national electrical demand (ECRA, 2014; SEEC, 2013). In Saudi Arabia, most mosques are equipped with either central or split- or window-type air-conditioning systems in conjunction with ceiling fans. In the vision for 2030, the KSA has expressed its concern for green buildings (KSA, 2016). One of its objectives is to increase the level of awareness, promote and consolidate efforts to achieve sustainable building and construction in KSA, including sustainable mosques. KSA has the largest number of mosques in the world (31 million). The number of mosques built by the government has significantly increased from 55,266 in 2008 to more than 102,580 in 2015 as KSA cities have witnessed an increase in urbanisation and architecture (Al-Howaimel, 2013; MIADG, 2017). However, many other mosques are under private management, indicating that the number of mosques dramatically increased by approximately 58.6% within 7 years between 2008 and 2015 with an annual average of 12%. This large number of mosques caused the Ministry of Islamic Affairs, Dawah and Guidance to issue ordinances to the Imams to rationalise electric energy conservation in mosques (Al-Hemiddi, 2004a).

A large number of KSA donors prefer to contribute funds for building small mosques rather than large ones. This phenomenon is attributed to the popularity and speed of construction of these small mosques in addition to their low cost and extreme need in some areas, especially in small towns and residential neighbourhoods. However, these mosques need to be carefully evaluated in terms of thermal performance and energy requirements because these issues have not been adequately investigated and addressed. The aim of this study is to measure and evaluate the indoor environment and energy efficiency of these small popular mosques.

Previous Studies

The thermal design optimisation of mosques in KSA is reported in a study by Al-Homoud (2009). The study defined the physical and typical operating characteristics of mosques, as well as the thermal optimisation of a medium-sized mosque in two hot-dry and hot-humid KSA cities of Riyadh and Jeddah. This study described the design guidelines for the optimum thermal performance of mosques in these two cities. The study concluded that the operating strategy of the HVAC system is extremely important in mosques to achieve the desired thermal comfort with minimum energy requirements. The study recommended further research to investigate the proper design and operation of other mosques.

Another study (Al-Homoud, Abdou, & Budaiwi, 2009) presented the results of a study designed to monitor the energy use and thermal comfort conditions of a number of mosques in the hot-humid climate of Dhahran City, KSA so that energy efficiency and the quality of thermal comfort conditions, especially during occupancy periods in such intermittently operated buildings, can be assessed accurately. The study concluded that in many situations, mosques are over-cooled or the HVAC system is kept running for a much longer time than needed. In other situations, thermal comfort is not achieved due to improper operation practises coupled with poor and insufficient maintenance and inefficient air-conditioning systems. Mosques represent a type of building characterised by a unique intermittent operating schedule determined by prayer times, which vary continuously according to the local solar time.

Abideen (1997) investigated mosques in KSA and concluded that reducing the cooling load of air-conditioned mosques in Jeddah City by utilising adequate passive means is possible. Furthermore, he found that the proposed passive cooling strategy secures savings of approximately 82% in air-conditioning energy, 50% in money, 28% in CO2 emission and 80%
in chlorofluorocarbon emission at the city level. Moreover, a study conducted by Al-Hemiddi (2004b) focused on the electric energy conservation in mosques. The study compared the electric energy consumption rates in two types of Jum’a mosques in Riyadh and Skaka, and concluded that the increase in the ambient temperature raised the energy consumption due to the use of an air-conditioning system. According to the study, architects should consider designing mosques based on environmental factors.

Mushtaha & Helmy (2017) conducted a study on the impact of building forms on thermal performance and comfort conditions in religious buildings in hot climates of United Arab Emirates. The study was conducted using energy simulation software to investigate the impact of passive parameters, such as shading devices, thermal insulation and natural ventilation, on thermal performance and indoor thermal comfort. The findings confirmed that using passive design alone would not only help achieve thermal comfort but also reduce the annual energy consumption by 10%. By integrating a hybrid air-conditioning system as another supporting approach, the annual energy consumption could be reduced by 67.5%, which allows the design of a small HVAC system.

**Local Climatic Condition in Najran, KSA**

Najran is a city in southwestern KSA near the border of Yemen (Figure 1). It is the capital of Najran Province and is located at 17°29'30"N latitude and 44°7'56"E longitude. Designated as a new town, Najran is a fast-growing city in KSA; its population has increased from 47,500 in 1974 and 90,983 in 1992 to 246,880 in 2004 and 569,875 in 2016 (GAStat, 2016).
Najran has a desert climate where no rainfall occurs during the year. The average annual temperature is 25.74 °C and the average rainfall is 133 mm. The driest month is June with 0 mm of rainfall. The greatest amount of precipitation occurs in April with an average of 75 mm. The warmest month of the year is July with an average temperature of 33.2 °C. The lowest average temperature in the year occurs in January at 18.5 °C. Figure 2 shows the maximum, minimum, average dry bulb temperature, total rainfall, wind speed and average relative humidity for Najran City where the case studies are conducted. Moreover, in KSA, Najran has the highest daily solar radiation of more than 6.9 kwh/m2/day (Khan, Asif, & Stach, 2017). As this energy cannot be dissipated efficiently, it creates discomfort and becomes a heat gain problem, and this heat needs to be extracted from the building space using an HVAC system.

Methodology
Small mosques, with most having an approximate area of 200–300 m2 designated for prayer, are distributed across the neighbourhoods of Najran. Small mosques account for 90% of the total number in KSA. The main objective of this study is to investigate the thermal performance and energy consumption of small mosques in the hot-arid climate of Najran City, KSA. The research methodology is divided into three parts as follows:

Description of the Case Study
In this study, Al-Oraysah mosque has been selected to represent the common type of a single-zone daily prayer mosque. Figure 3 shows the mosque plan. Moreover, Table 1 shows the criteria of representative mosque selection and their physical and operational characteristics.

Field measurements
The impact of the building envelope components in indoor air temperature and relative humidity was measured. For this purpose, continuous environmental monitoring was conducted using data logging equipment Extech RHT 20, which can automatically recognise them and respond with compatible functionality. Data loggers (Figure 4) were used to collect internal and external environmental data. A continuous measurement was undertaken in the
centre of the prayer hall during the hottest period on 17–27 August 2017. The parameters were measured at 10-minute intervals and recorded continuously.

**Energy Usage**

The electric energy of mosques for the full 12 months of 2017 have been collected from electricity bills. The monthly consumed energy represent the indoor environment, building envelope performance and operation behaviour. Moreover, the annual energy consumption of the investigated mosques has been compared with (a) results collected from previous studies and (b) results collected from the Saudi Electricity Company of two mosques in Najran.

---

**Table 1. Description and physical data of Al-Oraysah Mosque.**

<table>
<thead>
<tr>
<th>Type of use</th>
<th>Name of Mosque</th>
<th>Area M²</th>
<th>Capacity</th>
<th>Structural System</th>
<th>Mechanical and Lighting Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>(prayer)</td>
<td></td>
<td></td>
<td>(Number of Worshippers)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>Al-Oraysah</td>
<td>220</td>
<td>250</td>
<td>200-mm concrete block walls</td>
<td>4 floor-mounted split units</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total WWR 6.5%</td>
<td>6 window-type A/C units</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>150-mm reinforced concrete roof</td>
<td>6 wall split units</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No thermal insulation</td>
<td>6 ceiling fans</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The net height of the prayer hall is 4800 mm.</td>
<td>48 fluorescent lamps 40 W</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Evaluation of Number of Worshippers

Figure 5 shows the average number of worshippers during the five prayer times for typical and Friday times. The maximum occupancy of the mosque occurs during Al-Eshaa prayer on typical days and Fridays. However, this occupancy does not exceed 25% of the actual capacity of the mosque. The lowest number of worshippers occurs during noon prayer (Al-Dhohur) when the outdoor air temperature is the highest and most of the residents are in their workplaces.

![Number of Worshippers](image)

Figure 5. Number of worshippers during prayer times

Thermal Behaviour of Mosque

Figure 6 shows the indoor/outdoor air temperatures and RH for one week of continuous field measurements. In addition, Figures 7 and 8 show the patterns of two typical days (Friday and Tuesday) for in/outdoor air temperatures and RH for further investigation. The results in Figure 6 shows that the outdoor air temperature is always above the requirement of the optimum comfort temperature. In this study, the comfort temperature ranged from 23 °C to
26.5 °C during the summer, autumn and spring seasons. This comfort range is determined according to ASHRAE thermal comfort standard, considering occupants with light activities and light summer clothing. Thus, the HVAC system was the suitable option to be operated during prayer times to maintain the indoor environment of the mosque. HVAC works for approximately 40–60 minutes for Al-Fajr, Al-Dhoor and Al-Asr prayer times and continuous two and a half hours for the Al-Maghreb and Al-Ishaa prayers. On Friday, the HVAC system is not operated during Al-Dhoor prayer because no Jomaa prayer is performed in the mosque. The figure also shows that whenever the HVAC system is switched off, the indoor air temperature increases directly. This observation means that the building envelope is extremely poor in terms of thermal performance because it is not insulated. In addition, air infiltration is high due to open doors during prayer times.

Therefore, the manual operation of the HVAC system contributes to less electricity use because the total operation time is approximately four to five hours daily in summer. Furthermore, this control system, which varies between on and off, makes the HVAC system unable to sustain the indoor temperature to reach the thermal comfort zone during the 30 minutes of prayer occupation time.

**Monitored energy use**

Figure 9 shows the monthly energy consumption of the mosque for 2017. The results indicated that the monthly energy consumption varies from month to month according to the outdoor temperature and climate condition. The maximum consumption is recorded during the summer months, with an increase of approximately six times between June and January. The results show that the annual electrical energy consumption of the mosque is 32,880 kWh/year (Figure 9). In the prayer area (220 m²), the total consumption per square metre is approximately 150 kWh/m²/year. Furthermore, the current study found that the average daily consumption of the mosque is 91.3 kWh/day. The average consumption per worshipper per day is less than 0.5 kWh/prayer/day.
Table 2 summarises the total amount of energy consumption per square metre per year for six mosques in four cities all over the country. The results show that energy consumption varied from one mosque to another according to the climate condition, envelope materials, volume and type of operation because no standard determines the ideal energy consumption of mosque buildings. Therefore, the energy consumption of the case study is deemed to be average. However, if the building envelope components and the operation style were considered, then a huge saving potential in energy could be achieved.
Figure 9. Monthly electricity consumption

Table 2. Comparison of energy consumption per square meter per year for six mosques in KSA

<table>
<thead>
<tr>
<th>Type of compression</th>
<th>Previous studies</th>
<th>Field data</th>
<th>Case Study***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of Mosque</td>
<td>Owais Al-Garni*</td>
<td>Al-Quds**</td>
<td>King Fahd***</td>
</tr>
<tr>
<td>Location</td>
<td>Dammam</td>
<td>Riyadh</td>
<td>Abha</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>355</td>
<td>480</td>
<td>180</td>
</tr>
<tr>
<td>Energy Consumption Kwh/m²/year</td>
<td>186</td>
<td>297</td>
<td>109</td>
</tr>
</tbody>
</table>

* Al-Homoud et al., 2009  
** Shohan, 2015  
*** Collected and calculated by the researchers from the field.

Conclusions and recommendations

Based on the results of the study on the indoor environmental parameters and energy use, the following recommendations can be stated:

- The maximum occupancy rate does not exceed 25% of the actual capacity of the mosque, which results in reconsideration of the required size of the neighbourhood mosques.
- The operators in small mosques used to run the HVAC system only during prayer calls for Adhan. Therefore, thermal comfort is not achieved during times of peak thermal loads. HVAC must be switched on before the prayer time (30 minutes before Adhan).
- Air infiltration that causes considerable heat loss and gain should be limited in hot-arid climate. Therefore, windows should not be opened. Moreover, mechanical door closers should be installed to minimise heat gain through openings.
- Building envelope components play a major role in energy saving. Thus, the proper design and selection of mosque envelope components, especially their thermal insulation, are highly recommended.
• This study was conducted on mosques designed and operated in the hot-arid climates of Najran City. The aforementioned recommendations can be applied to all mosques in KSA.

ACKNOWLEDGEMENT

The authors are grateful to Najran University for supporting the publication of this study under grant number NU/ESCI/15/039. The authors also thank the administrative management of Al-Oraysah mosque for the assistance and cooperation provided.

REFERENCES


Investigating the Impact of Renewing Floor Coverings on the Energy Performance of Dwellings with Suspended Timber Floors, Tested under Controlled Conditions

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Abstract: Dwellings with suspended timber floors are commonplace in the UK, making up almost a third of the overall housing stock. Floor coverings, such as carpets and vinyl, are often used in these types of dwellings to achieve thermal comfort, aesthetics and energy. Over time, due to general wear and tear, the quality and performance of floor coverings can deteriorate. This deterioration affects the overall performance of these coverings as a whole and so it becomes necessary to replace them. Developments in the production of floor coverings and underlay have resulted in the opportunity to replace floor coverings with more robust materials, which can demonstrate improved energy efficiency.

The Energy House at the University of Salford is a full-scale replica of a typical UK home (pre 1920’s Victorian Terrace), contained within a controlled environment. This facility was originally fitted with a synthetic carpet and laminate on top of rubber-based underlay material. After 6 years of heavy use, all floor coverings within the house were replaced with new materials. Tests were conducted throughout the transition from old coverings to new, under steady state conditions; this included measurements of energy consumption, heat flux density, air tightness, and the global heat transfer coefficient.

The original floor coverings were found to improve the overall energy consumption by 2.7%, heat flux through the floor by 16.9%, air tightness by 3.3% and the global heat transfer coefficient by 3.0%. By replacing the original coverings with new materials, the improvement to the overall energy consumption rose to 4.8%, heat flux rose to 27.1%, air tightness to 6.0% and the global heat transfer coefficient by 5.0%. Thus, it can be demonstrated that by replacing old floor coverings for this building type, the energy performance of those coverings can be almost doubled.

Keywords: Building Performance, Pre-1920 Housing, Thermal Performance, Suspended Timber Floors, Retrofit, Floor Coverings, and Controlled Environment

Introduction

The UK has made a formal commitment to reduce the level of CO₂ emissions by 80% when compared to 1990, by the year 2050 according to the Climate Change Act 2008 (DECC, 2008), a significant portion of the CO₂ emissions currently are generated from domestic energy usage currently around 30% (BEIS, 2017). This leaves the housing stock in the UK, the subject of many ambitions to reduce energy usage and this minimise CO₂ emissions.

Whilst many consider that fabric and services retrofitting combined with behaviour change are an important way of meeting these targets (Swan, Ruddock, Smith, & Fitton, 2013), there is another aspect of energy savings which has not been addressed thoroughly in the literature, in the area of soft furnishings which have been proven in the past to have a positive effect on the energy efficiency of a building, the author has recently proven this in a paper around curtains and blinds in domestic properties with reductions in energy loss in windows being reduced by between 5% and 29% (Fitton, Swan, Hughes, & Benjaber, 2017). These type of energy savings given their very nature can also have significant effects on not only the energy performance of a dwelling but the thermal comfort levels present (Baker, 2008; Fang, 2001; Mcneil, Bulletin, & Zealand, 2016).

This paper examines the energy savings offered by floor coverings and their installation technique under controlled conditions at a whole house scale. Existing floor
covering materials – carpet and underlay in the majority of rooms and luxury vinyl tiles (LVT) with a timber base in the kitchen – were replaced with new carpets and underlay, and new LVT and a purpose made LVT underlay. Measurement under controlled conditions allowed for accurate measurements to be carried out with low uncertainty margins when compared to making these measurements in the field.

**Mechanisms affected by carpets and underlays, conduction convection and radiation**

The purpose of a floor covering can be many different things; to aid in thermal comfort (providing a barrier to a cold floor surface), to provide a comfortable surface for sitting and walking, and assist in the day to day cleaning of the property. This paper however is focussed entirely on the topic of the prevention of heat loss in a dwelling. Heat loss can happen through 3 mechanisms, conduction convection and radiation (Hens, 2012), we will examine only two aspects; thermal transmission through the floors (conduction) and infiltration related losses (convection).

Energy savings attributed to floor coverings are generally attributed to the following; Increase in the thermal resistance of the floor, any material added on the top of an unfinished floor will increase its resistance.

Increasing the airtightness of the dwelling itself will have the effect of minimising heat loss through warm air leaving the building though the floor structure and cold air entering. The process of re-fitting floor coverings to a high standard reduces the overall flow of warm air from the building by generating an air-tight seal around the boundary of the room. Figure 1 demonstrates such a fit using carpet grippers.

**Figure 1.** Underlay and carpet fitted using carpet grippers to form an air-tight seal around the edge of a room.

We will first examine the resistance of the element: The current way in the UK of defining the heat loss through a suspended timber floor is to use a U value, expressed in W/m²K, this gives the rate of heat loss from the heated side of an element to the unheated side. This is calculated using U-value =1/Sum of total resistance.

This process can be found explored in much greater detail on papers related directly at measuring heat loss in floors (Pelsmakers et al., 2017), this paper takes simpler approach in the point values are measured for transmission performance rather than attempting to scale these results out across the entire floor. This is illustrated by Pelsmaker’s findings which
were the result of a very detailed measurement campaign also carried out on the floor in the Energy House (Pelsmakers et al., 2017). This revealed a large variance in U-values over the ground floor of the property, ranging from 0.56 to 1.18 W/m²K, this is represented graphically in Figure 2 which shows the U values across the living room of the Energy House.

This is presented below in a theoretical calculation for a suspended floor with and without a floor covering:

### U-value of floor construction:

<table>
<thead>
<tr>
<th>Layer</th>
<th>d (mm)</th>
<th>λ layer</th>
<th>λ bridge</th>
<th>Fraction</th>
<th>R layer</th>
<th>R bridge</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19</td>
<td>0.130</td>
<td></td>
<td></td>
<td>0.170</td>
<td>0.146</td>
<td>Timber flooring</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.170</td>
<td>0.486</td>
<td>Rs (underfloor)</td>
</tr>
</tbody>
</table>

This study looks to investigate the impact of not only floor covering replacement, but the high standard of installation of those floor coverings on the overall energy efficiency of a dwelling.

**New carpets vs old**

 Carpets are subject to frequent wear and degrade over time. Any one of the following can be a cause to replace carpets (Gupta and Goswami, 2018):

- Loss of definition
- Fibre shedding
- Fuzzing / piling
- Shading / water marks
- Fading

![Figure 2. Linear interpolated U-values as a function of both bay (X-axis) and gable (Y-axis) wall distances. (Pelsmakers et al., 2017).](image-url)
• Soiling
• Stretching / rucking.

While these factors account for aesthetic defects in carpet material, the degradation of that material can also impact its thermal performance.

A compromise exists between fibre quantity and the space for static air between fibres (Bakker, 2018). Increased fibre quantity causes an increase in heat loss by conduction, while increased air space causes an increase in heat loss by convection and radiation, and so a balance between the two is necessary. As carpets degrade, this balance is disrupted, largely by the material’s ability to retain its original definition. Figure 3 shows how carpets piles are subject to deformation over time.

![Figure 3. Deformation of carpet piles over time; (a) New carpets, <7 treads, (b) Used carpets, >7 treads, (c) Old carpets, (d) Older carpets. (Dayiary et al., 2009).](image)

With time, as loads (P) are applied onto carpet piles, the bending of individual fibres moves gradually to the base as definition is lost. Eventually, fibres represent (d) in figure 3, reaching a stage called jamming. This is where deformation is at a maximum, spacing between fibres becomes a minimum, and heat loss through conduction peaks. The jamming process impacts material performance in three ways:

- Acoustic performance of the carpets is reduced.
- Thermal conduction through the floor is increased, reducing thermal performance.
- Perceived thermal comfort is reduced due to the increased heat loss through the floor.

Resiliency is the ability of a carpet and or underlay to return to its original upright position, retain its definition and in turn maintain its performance. It is considered one of the most important characteristics of carpets (Chaudhuri, 2018). Common materials used in carpet making, which demonstrate resiliency, are Nylon and wool. Other materials used in carpet making, but have a reduced resiliency are acrylic, polypropylene, polyester, cotton and silk. Given the different structural properties of these materials and the varying sub-structure of carpet (pile fibre content vs air spacing), the thermal properties of carpets can vary. As such, the time taken for the thermal and acoustic properties of carpets to degrade will also vary.

While aesthetics play a large part in determining when carpets and floor coverings are replaced, these three performance factors are often disregarded in the process of replacement. This work investigates the impact of replacing carpets on the overall energy performance of the dwelling as a whole, and asks the question as to whether these performance factors should be taken into consideration.
How are carpets currently dealt with in models and regulation?

There is some discrepancy about how floor coverings are dealt with regards to energy modelling in the UK. SAP (The Government’s Standard Assessment Procedure for Energy Rating of Dwellings), the UK’s regulatory energy modelling package of new and existing dwellings makes no mention of floor coverings within its documentation, so one may presume that often the resistance added by floor coverings is omitted by designers (BRE, 2011). BR443, which is the recognised guidance in the UK for calculation of U-values declares that “floor coverings are not included in the calculation; but it is permissible to include them if their properties are adequately defined” (Anderson, 2006). This gives the option but not the requirement to incorporate floor coverings into the U-value calculation.

Method

The Energy House test facility was used to conduct three key tests to determine the change in energy performance of a dwelling following the replacement of all floor coverings within the home. These three tests were:

- A whole house global heat loss test.
- Heat flux density measurements of the ground floor.
- Blower door tests to determine the air permeability of the building.

Each of the tests were carried out under controlled conditions, for each of the test scenarios: with old floor coverings, with no floor coverings (bare floorboards), and with new floor coverings. Energy consumption was also monitored during each of the test periods.

Description of facility and construction

The Energy House test facility at the University of Salford is a full scale replica of a pre-1919 UK Victorian end terrace house. The house was built inside a climate controlled chamber, where all environmental conditions inside and outside the building can be controlled. The facility is shown in figure 4.

![Figure 4. The Energy House test facility at the University of Salford.](image)

The majority of materials used to build this house were reclaimed, and the construction carried out in the typical tradition used at the time. This type of house is representative of a
large proportion of the UK’s existing housing stock (NIHE, 2009; ONS, 2010 & 2011), which is expected to make up around 80% of the total housing stock in the UK by 2050 (SDC, 2006). A more in depth description of the building can be seen in work by Marshall et al., (2018).

The core feature of this research facility is that the building exhibits extremely similar behaviour to those found in the field, and so modifications made to the fabric of the Energy House deliver realistic measurable changes to energy performance.

The tests discussed in this section benefit from steady state conditions and are a requirement for co-heating and heat flux density measurements for the accurate calculation of heat loss coefficient (HTC) and U-value. By controlling the environmental conditions in the house and chamber, it was possible to achieve quasi-steady state conditions to facilitate these tests.

**Whole house global heat loss test**

The electric co-heating method as described by Johnston et al. (2013) was used to determine the heat transfer coefficient (HTC) of the Energy House at three different stages of refitting the carpets within the house – with old carpets and underlay, with no carpets or underlay, and with new carpets and underlay. The HTC is a measure of the global heat loss from a building and consists of both fabric and ventilation losses.

Quasi-steady state conditions are required to carry out the test, with a significant temperature difference between internal and external spaces to ensure mono-directional heat flow through the building envelope. To achieve this, the external temperature in the chamber was held at a constant temperature of 4.3 ± 0.5 °C. Internal temperatures were artificially raised to 21 ± 0.5°C using electric fan heaters in each of the six thermal zones within the house. Additional fans were also used to circulate air around the building to reduce the effect of stratification.

The heat transfer coefficient can be calculated using:

\[
HTC = \frac{Q_{avg}}{T_{i,avg} - T_{e,avg}}
\]

Where \( Q_{avg} \) is the average power input from all heaters (W), \( T_{i,avg} \) is the average internal temperature of the building (°C), and \( T_{e,avg} \) is the average external temperature (°C). Note that solar input typically used in this equation is not used for this study.

The building was allowed to reach quasi-steady state conditions following the establishment of each test scenario (old coverings, no coverings, new coverings), following which data was collected for multiples of 24h. Data from the final 24h of each test period was used to calculate the HTC.

**Heat flux density measurements**

Heat flux plates were affixed to the bottom of the floorboards of the ground floor – in both the kitchen and the living room. Four Hukseflux HFP-01 plates were used per room, to give an indication of the heat flow through the ground floor of the building. Note that the ground floor of the Energy House is a suspended timber floor, with a 300mm air gap.

Data from these heat flux plates were collected during the same test period as the electric co-heating test. The final 24h of heat flux data were used to calculate an average per room, for each of the test scenarios.
**Blower door tests**

Following each electric coheating test, blower door tests were performed on the Energy House. These tests were carried out to the standards of ATTMA Technical Standard L1 (ATTMA, 2010).

An external doorway was fitted with a specialised frame, which holds a fan capable of pressurising and depressurising the building to create a pressure difference across the building envelope. Each test considered depressurisation at 50Pa, to calculate an air permeability in \( \text{m}^3/\text{h/m}^2 \). To achieve this calculation, the flow of air out of the building was increased to raise the depressurisation pressure by increments of 5Pa to 75Pa.

As per the ATTMA Technical Standard, all mechanical vents were sealed to ensure only the building’s natural permeability was captured during the tests. Results for each scenario were then compared.

**Results**

Four parameters were identified for each of the test scenarios; this included the Heat Transfer Coefficient for the whole building, the average heat flux through both kitchen and living room floors, the air permeability of the whole building, and the energy consumption over 24 hours.

**Results from the Electric Coheating Test**

Conditions within the house and within the chamber were maintained to facilitate this test, an example of this is shown in figure 5, which gives the temperatures for each room and the chamber during the test for the original floor coverings.

![Figure 5. Air temperature measurements during the final 24h of an electric coheating test, carried out using original floor coverings.](image)

Note that air temperature measurements were taken at the geometric centre of each room. Steady temperatures as shown in figure 5 were exhibited during all tests.
Average power input and average temperature differences over the 24h period were used to calculate the HTC using equation in section 3.2. Table 1 lists the HTCs calculated for each test scenario.

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Average Power Input (W)</th>
<th>Average Internal Temperature (°C)</th>
<th>Average External Temperature (°C)</th>
<th>HTC (W/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Floor Coverings</td>
<td>3450.42</td>
<td>21.13</td>
<td>4.24</td>
<td>204.29</td>
</tr>
<tr>
<td>Old Floor Coverings</td>
<td>3350.42</td>
<td>21.19</td>
<td>4.27</td>
<td>197.98</td>
</tr>
<tr>
<td>New Floor Coverings</td>
<td>3278.75</td>
<td>21.22</td>
<td>4.33</td>
<td>194.15</td>
</tr>
</tbody>
</table>

Table 1. Calculated Heat Transfer Coefficient for old floor coverings, no floor coverings and new floor coverings.

Results demonstrate a reduction in the HTC of 1.94% when changing from old floor coverings to new floor coverings. Old floor coverings provided a reduction of 3.09% over bare floorboards, while new floor coverings provided a reduction of 5.0%.

The reduction in HTC is a combination of effects from improved fabric thermal performance and an improvement of the ground floor air tightness. The contributions for each are inferred from the following results of heat flux density measurements and blower door testing.

**Results from Heat Flux Density Measurements**

Heat flux measurements were consistent for both the living room and kitchen. Variations were observed between the data for each given the different type of floor covering used. Figure 6 shows an example of this in the 24h test period for the scenario with old floor coverings.
The data in figure 6 show that heat flux through the kitchen floor exhibits far more fluctuations than the living room floor. This demonstrates the difference between heat flow through carpet, LVT and their respective underlays. Fluctuations appear in the heat flux measurements of both kitchen and living room without floor coverings (bare wooden floorboards) and disappear in the living room with the installation of the new carpet.

The average heat flux throughout each test is consolidated in table 2, with the difference due to changes in floor covering.

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Average Heat Flux Living Room (W/m$^2$)</th>
<th>Difference from No Covering</th>
<th>Average Heat Flux Kitchen (W/m$^2$)</th>
<th>Difference from No Covering</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Coverings</td>
<td>11.34</td>
<td>-</td>
<td>9.78</td>
<td>-</td>
</tr>
<tr>
<td>Old Coverings</td>
<td>8.56</td>
<td>24.51%</td>
<td>9.22</td>
<td>5.72%</td>
</tr>
<tr>
<td>New Coverings</td>
<td>8.12</td>
<td>28.39%</td>
<td>7.87</td>
<td>20.40%</td>
</tr>
</tbody>
</table>

Table 2. Average heat flux data for the kitchen and living room, for each test scenario.

Results from the heat flux density measurements reveal that floor coverings reduce heat flux through the ground floor significantly. In the case of living room carpets, the old and new carpets provided a similar reduction to heat flux, with the new carpet having a greater impact. The new installation of LVT and the LVT underlay composite in the kitchen however, demonstrated a much higher reduction in heat flux over the old installation of vinyl with a timber base.

Results from Blower Door Tests.

Each of the blower door tests gave an output value for air permeability in m$^3$/h/m$^2$, based on the depressurisation pressures achieved around 50Pa and the air flow into the building.
required to sustain them. Table 3 gives the air flow and pressure measurements during each blower door test, with the resulting air permeability value.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Air Permeability (m$^3$/h/m$^2$)</th>
<th>Error</th>
<th>Difference from No Covering</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Covering</td>
<td>13.22</td>
<td>1.1%</td>
<td>-</td>
</tr>
<tr>
<td>Old Coverings</td>
<td>12.79</td>
<td>2.8%</td>
<td>3.25%</td>
</tr>
<tr>
<td>New Coverings</td>
<td>12.43</td>
<td>1.3%</td>
<td>5.98%</td>
</tr>
</tbody>
</table>

Table 3. Results from each blower door test.

Results from the blower door tests show that carpets, LVT and their underlays do impact on the air permeability of the building; not only the presence of floor coverings, but the quality of those fitted coverings. By replacing floor coverings within the Energy House, it was possible to reduce the air permeability by 2.82%, a reduction which almost certainly contributes to the overall HTC reduction of the building.

Results of 24h Energy Consumption

Throughout each of the tests, the energy consumption in the final 24h of data collection was measured. This was compared to give an indication as to the possible energy reduction due to the changing of floor coverings. Table 4 lists the energy consumption measurements, and differences for each scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy Consumption (kWh)</th>
<th>Difference to No Coverings</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Coverings</td>
<td>82.81</td>
<td>-</td>
</tr>
<tr>
<td>Old Coverings</td>
<td>80.41</td>
<td>3%</td>
</tr>
<tr>
<td>New Coverings</td>
<td>78.69</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 4. Results from 24h energy consumption measurements.

Results from these rests demonstrate how, by replacing old carpets and vinyls with new, the reduction in energy consumption due to those floor coverings can be almost doubled.

Conclusion

All floor coverings – carpets and vinyl – of a replica Victorian UK terraced house were removed and replaced with new floor coverings. This process was carried out to assess the change in performance at whole building, and at building element level. Environmental conditions were controlled and maintained to facilitate quasi-steady state conditions.

Three test scenarios were used for the study: no floor coverings, old floor coverings and new floor coverings. Four energy performance parameters were then measured or calculated to assess the impact of each test scenario on building performance. These were the heat transfer coefficient, heat flux through the ground floor, air permeability, and energy consumption over 24 hours. Data from the final 24 hours of each test period were used to evaluate each of the energy performance parameters – with the exception of air permeability.

In all cases, results indicated that floor coverings improve the overall energy performance of a dwelling. In addition to the benefits observed from the old coverings, the
materials used in the installation of new floor coverings and the high standards of that installation saw a further increase in the benefits to energy performance.

By replacing the carpet, vinyl floor, and underlay coverings of a whole dwelling, using a high standard of installation, it was possible to reduce the global HTC by 1.94%, the heat flux through the floor by up to 14.60% (due to the replacement of vinyl and a timber base, with LVT and a purpose made LVT underlay), the air permeability of the building by 2.82%, and 24h of energy consumption by 2.14%.

Acknowledgement

The authors wish to thank Paul Young and acknowledge Interfloor for the generous donation of materials and labour used to carry out this test.

References

SDC, 2006. 'Stock Take': Delivering Improvements in Existing Housing. Sustainable Development Commission.
Implementation of BIM Technologies in Architectural Engineering Education

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Abstract:
The recent years have witnessed a rise in the demand for the adoption of Building Information Modelling (BIM) technology within the Architecture, Engineering, and Construction (AEC) Industry. BIM in the (AEC) industry has become an essential tool for facilitating processes throughout building design and life-cycle. For this reason, academic institutions are competing to provide their students with the required skills to operate BIM effectively. In the case of Oman, university-led BIM training is still at an early stage of implementation and development. However, several universities have been carrying out a wide range of competitions and courses to provide students with an experience in this domain. This article aims to investigate the application of BIM Technologies in architectural engineering education in Oman and to provide a summary of current trends in this area. The article aims to purpose practice guidelines and effective strategies for teaching BIM (Building information modeling) from an academic perspective. It describes how BIM was utilized throughout the architectural teaching and design process in architecture and interior design department, at the University of Nizwa. Moreover, it presents several case studies which offer a pioneering example in the adoption of BIM to enhance the student skills and familiarize them with advanced technologies relevant to their future careers. Such examples could pave the way for prospective partnerships between academic institutions and the (AEC) industry. Findings of this article highlight the importance of implementing BIM technologies in architectural education. It also emphasizes the value of BIM for the design process in the currently competitive working environment.

Keywords: BIM, Technologies, Architecture, Education.

1. Introduction
BIM Technology (Building Information Modelling) is changing the way projects are built and how business is conducted within the Architecture, Engineering, and Construction (AEC) Industry. In addition, many companies throughout the world require professional employees who can work effectively in projects involving BIM processes. Although BIM has promising applications for teamwork projects, the status quo of its integration in academia is hindered by several obstacles such as the lack of time, resources, and space in the educational curriculum, inappropriate materials as well as the clear shortage of qualified staff and professional specialists to satisfy the need. This paper aims to propose practice guidelines and effective strategies for teaching BIM (Building information modeling) from an academic perspective. The need for a time-efficient design along with the increasing amount of project documentation and the involvement of multi-disciplinary participants in the life cycle of a project requires a design integration tool. The integrated BIM tool of a building or structure becomes an essential tool for facilitating all processes throughout the building life-cycle. This feature allows designers to build a BIM model which is an intelligent object contains a large number of interrelated information from different sources (Talapov, 2011). BIM is a process that involves designing, constructing and operating a building or infrastructure using electronic object-oriented information.
Oman is considered in an early stage of the process of integrating BIM technology into design and construction practices when compared to other countries such as USA, UK Singapore. On the national level, Oman has taken the following steps towards the implementation of BIM:
1. In 2016, the Ministry of Regional Municipalities & Environment issued the decree on the approval of the plan for the adoption of information modeling technologies in the field of industrial and civil construction.
2. In 2018, the implementation of information modeling technologies was approved by Muscat Municipality for buildings at all stages.
3. Standardization and BIM rules for the phases of buildings life-cycle were the most important aspects of the approved document.

These actions illustrate how legislative authorities in Oman had reached an understanding of the need to prepare specialists to use information modeling in the field of industry. This emphasizes the necessity for educational standards and new programs to meet the rising demands. The current state of the educational system cannot timely tackle such obstacles which are further intensified by the lack of a practical education of BIM technologies in universities. Therefore, it is important to introduce innovative technologies in the educational process to better prepare specialists with new professional skills. The College of Engineering and Architecture at the University of Nizwa has launched a new educational program in 2018 to teach state of art technologies in the field of architecture and interior design where experienced instructors train students to use BIM technologies. In this paper, the author will demonstrate the utilized teaching methodology in this program and present several projects carried out by students of the department of architecture and Interior Design.

2. BIM platform

2.1 Advanced IT technologies in the industrial field
The fast-paced advances of information technologies and electronic industry have formed a strong foundation for a revolutionized artificial intelligence applications and interdisciplinary projects. These advances have a strong impact on all sectors of the economy and are quickly expanding in domains especially in architectural and construction practice. The technology of building information modeling is directly associated with these innovations and go further in developing recent trends. Examples of how advanced IT technologies are integrated with BIM could be seen in Cloud Technology, Smart House, (VR/AR) Virtual and Augmented Reality, 3D Scanning of the terrain, 3D Printing, Artificial Intelligence. (Krivonogov, A et al, 2017)

2.2 BIM growth
According to Autodesk, one the leading corporations in the BIM software market, the world currently lives in an era connected to BIM processes and information transmission throughout the life cycle of a certain project. In this context, CAD was the first era of documentation, and now is the era of optimization by BIM. Table 1. sheds the light on the levels of BIM in terms of maturity.
Table 1. Building Information Modeling (BIM) levels.

<table>
<thead>
<tr>
<th>BIM Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0 (CAD)</td>
<td>It is defined as an unmanaged CAD, likely to be 2D design papers, information by traditional drawings, separate sources of information.</td>
</tr>
<tr>
<td>Level 1 (2D &amp; 3D)</td>
<td>It is described as a mix of 2D and 3D information with a collaboration tool providing a common data environment (exchange of information in different formats).</td>
</tr>
<tr>
<td>Level 2 (4D &amp; 5D)</td>
<td>It is described as collaborative BIM. Federated model information is shared within a Common Data Environment.</td>
</tr>
<tr>
<td>Level 3 (I BIM)</td>
<td>It is likely to be a fully integrated model with interoperable data where all participants working from a single stored model (web service or cloud).</td>
</tr>
</tbody>
</table>

Furthermore, the integrated BIM models consist of a comprehensive description and facility management to ensure high collaboration work environment for all participants in the development and implementation of the project. This technology allows the user to visualize and analyse the future object with the selected materials. It also provides him myriad tools to manage cost estimation, optimization to the constructive part, clash detections, architectural solutions information extraction, spreadsheets as well as an intelligent model for the further operation of the facilities which probably raises of the project at all its life-cycle. Thus, BIM model could be considered as a multidimensional platform with different scenarios and uses. The components of BIM technologies could be tied to planning, design, construction and further operation stages. Moreover, a building information model can be used for the following purposes: (Azhar, S et al, 2012)

1. Visualization
2. Fabrication and shop drawings
3. Code reviews and forensic analysis
4. Cost estimating and quantity surveying
5. Construction sequencing and energy analysis
6. Facilities management
7. Conflicts, interference and collision detection

3. BIM in the architectural educational program

3.1 Practical methods of the teaching

The department of architecture and interior design in the University of Nizwa has a clear objective of raising the awareness of BIM and the practices involved especially through practical skills. This is achieved by providing innovative educations programs which are carried out by experienced instructors in the field of Computer Aided Design (CAD), the applications of BIM technology to building projects. The author is the coordinator for the professional BIM courses. The main aim of the courses is to introduce BIM technology as a mean of supporting the building’s life-cycle, particularly directed to the activities of design, construction and maintenance. Students are taught about different software application including relevant sections in such disciplines as “The Architectural Design”, “Built and environment” and “Interior lighting technologies”. Furthermore, Instructors have developed a system that provides a thorough understand of the principles of Building information modeling.
application through various strategies, practice methods and courses which can be grouped into seven types as the following:

1. Initially, BIM is taught in courses related to Digital Graphic Representation. The introduction to the CAD (Course: ARCH 204: Digital Graphics I) with modern software tools in the field of BIM such as Autodesk Revit and Graph iSOFT ArchiCAD. The purpose is to develop skills of BIM modeling and obtain a solid foundation in BIM concepts. Autodesk 3Ds Max and AutoCAD packages are also used to support the learning process. The BIM tools could be taught through laboratories, workshops and lectures supported by demonstrative examples to illustrate the successful implementation of BIM technology in the AEC industry.

2. BIM tools are generally integrated with design studios and building technology courses. This practical method varies depending on the level of design course to gain the required skills. The purpose is to learn about other BIM tools and advanced techniques while strengthening the skills of BIM modeling such as parametric design, building systems, sustainability, 3D detailing, establishment of specifications, list of materials and documentation generation. (Barison, M et al, 2011)

3. New courses have been proposed for the present year regarding to Management Construction. The first one is “Professional Collaboration of BIM in AEC Industry” which aims to develop skills of a BIM manager at various levels and sectors of the AEC industry. This course includes a further experience to BIM techniques such as interoperability, BIM management and team process. The second course focuses on tackling issues related to the implementation of BIM in the AEC sector and specifically on computer science knowledge concerning the BIM paradigm. This course focuses on the limitations of the model BIM interoperability, generation of architectural model, analysis of conflicts between different models and BIM strategy in education as well as a full BIM case study (Sampaio, Z, 2015). Moreover, several projects are also used to introduce the student to the principles of 4D and 5D modeling through the development of project concepts and buildings life-cycle.

4. Comprehensive discussions on the best work practices in the field of AEC Industry were prepared. This was followed by an attempt to build up a further understanding on analysing certain projects carried out with BIM. (Krygiel, E et al, 2008)

5. Site visits have been conducted to the locations of certified projects according to the ECO and GREEN standards in Nizwa city and other regions. Furthermore, to examine a model case study on features and facilities related to BIM implementation, students have visited Bustan Oman (ECO House) to study the experience of building which was full constructed with BIM tools and specialists.

6. Classes included also a cooperation with organizations implementing “Smart House System” in according with green standards with experts on energy-efficient housing construction. Instructors regularly invite experts from leading enterprises in the field of energy-efficient housing construction to meet students on workshops and seminars, such as companies and many others. (Krivonogov, A et al, 2017)

7. National Conferences and roundtables have been organized with the participation of researchers and graduates especially concerning scientific topics on advanced technologies
and innovative graduation projects. Recently, college of engineering and architecture has organized the “8th National Symposium on Engineering Final Year Projects” under the title “Graduation Projects, Towards Innovation and Technology” which was held on 2nd of May 2018 at University of Nizwa. In addition, architecture and engineering department has organized several scientific and professional seminars organized by companies that provide innovative materials and modern technologies. Furthermore, it has participated in major national and international exhibitions along with student’s participation in international competitions. In this context and during the recent years, students of University of Nizwa have made strong progress concerning acquiring BIM modelling skills not only throughout the Sultanate of Oman, but also expanded to GCC regions.

3.2 Examples of students’ projects using BIM technology

This section describes several projects which have been implemented by BIM technology. These works are related to real projects, educational, industrial and residential buildings. The first example shows a case study explaining the design stages of a country house in Al-Akhdar Mountain in Nizwa. The project was entirely made using Autodesk Revit in the form of a digital 3D model to determine the appropriate parameters of each element. The main objective of this project is to initially build up an understanding of BIM technology, obtain the required skills to handle the BIM tool as well as achieve the design quality and production time of the project, as shown in Fig 1. The focus of this project is to effectively train students on the applications of BIM software which is Autodesk Revit software. Another significant purpose is the development of the architectural model. Students could obtain a good grounding in the use of libraries with its standard components (parametric elements). These Libraries can easily be defined, copied and edited to create additional elements (walls, slabs, roofs, ceilings, doors and windows...etc) as well as extract schedules, spreadsheets and other estimating packages for a specific project.

Figure 1. Stages of designing a country house in Al-Akhdar Mountain in Nizwa.

Figure 2. illustrates the 3D presentation of International School in Nizwa, developed for the Ministry of Education. The work was presented at the “8th National Symposium on Engineering Final Year Projects” to introduce the BIM technology role in the design quality
and final production of the project. The project focused on capacities of Autodesk Revit used in this case study in term of 3D visualization.

Fig 2. 3D presentation of International School in Nizwa.

Fig 3. shows a conceptual design of a Children Museum which is located at Al-Qurum Nature Park of Sultan Qaboos Street in Muscat. The museum consists of two domes with different sizes. The purpose is to redesign the existed layout and create a comfortable environment to meet the new design requirements. A new function was proposed and developed to accommodate three open spaces, the human living space, physical space and environment space. The project was designed to meet the children environmental requirements and energy efficiency (Smart House). The project focused on capacities of BIM software used in the development and visualization of the interior model.

Figure 3. Visualization of the “Children’s Museum” in Muscat.

Figure 4. demonstrates a case study of a Farmhouse near Al-Mouj in Muscat. The students must develop a full project, using BIM software, while considering both engineering and architecture aspects. The first phase comprises the modeling of the project in Autodesk
Revit Architecture, based upon AutoCAD drawings. This stage of BIM modeling relies on precise placement of parametric objects along the auxiliary grids and levels to produce the 3D model (modeling process). After producing the model, all renderings and other viewing schemes are produced effortlessly. Autodesk Revit tools were applied at different levels and compared to the traditional 2D-3D CAD workflow. This case study highlighted BIM model’s ability to reflect the materials and the nature of building elements that were not present in 2D CAD. As a result, the project forms a basis for the comparison between workflow and procedures when adopting BIM as opposed to traditional 2D CAD drawings or 3D Models (3D Studio Max or Sketch Up).

In the second example, the students were requested to develop a simple simulated case, to obtain enough skill to operate the appropriate software in the future and use them on further complex projects, as shown in Fig 5. Although BIM model was generated in Autodesk Revit, the building model had considered only the architectural part of the building. In addition, at the end of the modeling process, the 3D model file was created and required in other formats for the matter of transfer. Finally, to improve the visualization aspect, Sketch Up and 3D Studio Max was used to producing 3D renderings of the project.
In Architectural Autodesk Revit course, students should explore up-to-date knowledge relevant to BIM technology. On completion of the course, the students will be able to present their design proposal, in the 3D software environment, in a professional manner. The main focus of the course is to develop necessary skills to effectively use Revit 3D environment, apply it to their design proposals, recognize BIM technology practices associated with CAD and evaluate their work and that of their peers. Assessment of the course includes, but not limited to, assignments, quizzes, in-semesters, final examination, projects and other types of assessments.

Table 2. Schedule of the project process in Architectural Revit Course.

<table>
<thead>
<tr>
<th>Description</th>
<th>1st Month</th>
<th>2nd Month</th>
<th>3rd Month</th>
<th>4th Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Creating project &amp; levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Adding foundation walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Adding topographic-building bad</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Creating exterior &amp; interior walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Adding furniture and plumbing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Adding doors &amp; windows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Creating floors &amp; curtain walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Creating stairs &amp; railings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Finalizing floors &amp; walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>11 Adding ceilings and lighting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Creating tags &amp; annotations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 Dimensioning, detailing &amp; drafting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Scheduling &amp; material take off</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>15 Creating a Solar Study</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Creating parts &amp; families</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Graphic display options</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 Presenting &amp; exporting to 3ds Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19 Setting location &amp; environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Render settings &amp; Adjusting</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

4. Conclusion

This paper provided a summary of current trends in modern technologies in Architectural Engineering Construction (AEC) industry and their influence on the education process. In this context, it demonstrated ways in which digital modeling of a building with BIM technologies can be implemented to the students’ education curriculum. In addition, for more extensive use of BIM technology, it is essential to develop educational standards and curriculum of
universities. The department of architecture and interior design in the University of Nizwa introduced new strategies to better prepare future specialists in the field of digital architecture through training students on BIM-modelling. These strategies are an attempt to develop new educational program “Digital Architecture in ECO Construction”. Moreover, this paper has briefly described the system that allows instructors to comprehensively teach the principles of environmental design and information modeling through the practice methods.

In conclusion, to respond to the rising demands on implementing BIM in Architectural Engineering Education, instructors should consider the following strategies:

1. Identify the BIM skills of the students and provide a list of them of a BIM specialist.
2. Apply the goals of each level in BIM practical teaching such as laboratories, lectures, discussions, workshops, presentations, case studies reviewing and site visits.
3. Facilitate design studios with the support of professionals in the field such as supervisor, assistant professor, IT assistant and specialist from industrial professionals.
4. Support the teaching resources with Industry Foundation Classes which include new courses and appropriate BIM tools.
5. Form a partnership for knowledge transfer between universities and industry to better promote BIM and gain benefits and experience.

References


Building Information Modelling (BIM) application in relation to embodied energy and carbon (EEC) considerations during design: A practitioner perspective

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Abstract: Buildings’ carbon emission reduction efforts in buildings have mainly been focused on operational energy reduction and, as operational energy is reduced, embodied energy and carbon (EEC) becomes more significant. However, there is currently a lack of legislation and guidance relating to embodied carbon in buildings. This, together with the United Kingdom (UK) construction industry fragmentation, creates a significant barrier to dealing with EEC during building design. In this context, Building Information Modelling (BIM) empowers communications and stores information into one single digital model and has therefore potential to facilitate EEC considerations to be included in building design.

This research takes a qualitative approach and looks at the design process in relation to EEC considerations and BIM application and how the latter can facilitate the inclusion of EEC in design considerations. Through semi-structured interviews with the construction industry professionals, this research investigates BIM application in relation to EEC information during design. EEC’s current role in building design and the drivers and challenges EEC considerations are being mapped. EEC information processes and how BIM facilitates EEC information exchange and storage as well as the actors involved are revealed. The overall aim of this research is to inform practice and policy to enable EEC reduction through BIM and meet overall carbon targets.

Keywords: BIM, embodied energy, embodied carbon, building design process, industry perspective

Introduction

Buildings are great contributors to carbon emissions and account for 36% of CO2 emissions in the European Union (European Commission 2018). There is therefore a worldwide effort to reduce carbon emissions from buildings. In the UK, the Government’s vision is to reduce greenhouse gas emissions in the built environment by 50% by the year 2025 (HM Government 2013). Buildings’ carbon emissions can be split into two categories, Embodied Carbon (EC) and Operational Carbon (OC). EC relates to the building construction which includes the manufacture, transport and installation of building materials (Sassi 2006) whereas OC relates to the building operation, which includes heating cooling and lighting requirements in order to meet comfort levels (Yohanis and Norton 2006).

Historically, OC accounts for a greater proportion of the overall building lifecycle carbon emissions and therefore carbon reduction efforts in the built environment have mainly been focused on OC. However, as buildings become more efficient and their OC decreases, EC will have an increased proportion of the overall building lifecycle carbon (Capper et al. 2012; Shrivastava and Chini 2012; Iddon and Firth 2013; Doran 2015). For low OC designs, EC has also been observed to increase not only as a proportion of the overall lifecycle carbon, but as an actual carbon figure due to increased use of materials for achieving low OC building designs (Winther and Hestnes 1999; Thormark 2002; NHBC Foundation 2011; Basbagill et al. 2013; Doran 2015).

Although EC becomes more important as OC is being reduced, there is currently a lack of legislation, consistent methodology and availability of comparable data in relation to EC (Capper et al. 2012; Royal Institution of Chartered Surveyors 2012; Sophie Chisholm 2015).
Further to this, the UK construction industry attitude and limited knowledge about EC as well as the industry’s observed fragmentation, creates a significant barrier to dealing with EEC during building design.

Building Information Modelling (BIM) has been introduced to the construction Industry as a new collaborative way of working that enables information storage and exchange within the BIM model (Mahdjoubi et al. 2015), facilitates data management (Shrivastava and Chini 2012) and most importantly facilitates stakeholder collaboration by providing a procedural shift (Succar 2009, 2013; HM Government 2015).

This paper presents the initial findings of a wider research project which investigates the potential of BIM to facilitate EC to be included into building design. This research takes an ethnographic approach that uses building projects at their design stage as case studies and includes interviews, meeting attendance and document analysis as the main data collection methods. In this paper, the findings from initial interviews held with industry professionals in the building construction industry are presented. Through these interviews, EC’s current role in building design and methodologies used for its calculation are investigated and the challenges in the process are revealed. The potential for EC inclusion in the design process through BIM application is explored from a participant point of view.

Method

This research included interviews with construction industry professionals which discussed the professionals’ perceptions about the role of EEC in building design, what motivates professionals to include EC as a consideration in design and how this changes for different project aspects, such as procurement routes, building uses and different clients. The information used for EC calculation of projects is also investigated focusing on when information exchanges that relate to EC take place, who gets involved in these information exchanges and what sources are used. The current drivers and challenges encountered by professionals in the process of information exchange and calculations for EC are outlined. Finally the BIM application and its potential to facilitate the inclusion of EC in building design is presented from a practitioner point of view. The interview topics are included table 1.

<table>
<thead>
<tr>
<th>Table 1 Interview topics</th>
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<tbody>
<tr>
<td>Participant background information</td>
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</table>

Four one hour semi-structured interviews were conducted. One interview was conducted face to face, while the others were conducted via real-time video conferencing tool called ‘Blackboard Collaborate’ and only included voice and not video. The professionals that participated in the completed interviews were two Life Cycle Assessment (LCA) consultants, one general sustainability consultant with expertise on BREEAM assessments and one architect. A future phase of interviews is planned to include structural engineers, quantity surveyors and BIM experts. Participant background information includes profession, company type, and types of projects and clients are included in table 2. The interviews were transcribed and the data was analysed using a qualitative data analysis computer software.
(NVivo 11). Thematic coding was used to compare participants responses in relation to the interview topics (table 1) and new codes emerged from the participants’ responses.

**Table 2 Participant background information**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Profession</th>
<th>Years of experience</th>
<th>Company Type</th>
<th>Project types</th>
<th>Client types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LCA Consultant</td>
<td>10 years</td>
<td>Global Sustainability Consultancy</td>
<td>All</td>
<td>Mostly big private developers</td>
</tr>
<tr>
<td>2</td>
<td>LCA Consultant</td>
<td>5 years</td>
<td>Environmental Consultancy with focus on LCA (SME)*</td>
<td>Mostly commercial</td>
<td>Mostly private clients</td>
</tr>
<tr>
<td>3</td>
<td>Sustainability Consultant</td>
<td>15 years</td>
<td>Sustainable Design Consultancy (Micro-enterprise)</td>
<td>All</td>
<td>Both private and public</td>
</tr>
<tr>
<td>4</td>
<td>Architect</td>
<td>8 years</td>
<td>Architectural Practice (SME)*</td>
<td>Most types excluding small domestic</td>
<td>Both private and public</td>
</tr>
</tbody>
</table>

* SME: Small Medium Enterprise

**Interview Results**

**The role of EC in design decisions and what drives EC considerations**

The role of EC in design decisions and the parameters that affect it were considered for different procurement routes, types of building projects and clients. It was found that the role of EC is mostly influenced by the client rather than the procurement route of the project according to all interviewees. Even for Design and Build procurement where the contractor has more control over the final product delivered, contracted deliverables and targets still need to be met. The contract and targets therefore play the most important role and are set by the client at the beginning of the project; interviewee 2: ‘As long as the right conditions are set by the client either in the form of contractual obligation but also the particular type of team relationships and hierarchy and organisation each project follows it is effectively down to that’, interviewee 4: ‘It depends what’s in the contract, if a specific requirement for EC is in the contract then the contractors can’ really change that. So Design and build is usually thought of as weak in terms of the contractors coming and doing whatever they want but it really depends’. In terms of types of projects, the role of EC in design does not change for different building uses, which was the belief of interviewees 1, 2 and 4, although Universities were found to demonstrate a high standard in terms of their sustainability ambitions for their buildings according to interviewee 3: ‘Universities again often have higher education funding council, there is a metric about rewarding about broad sustainability criteria, if you have a carbon management plan, what BREEAM rating, what your policies are. That can be very high level and can range from a variety of sustainability criteria. But an easy one is to say all new buildings will be BREEAM excellent, and I think that is why probably most universities have that in some degree’. Another participant found that for big projects, the larger developers/clients involved could afford the appointment of a carbon consultant which facilitated carbon...
calculations and there was a policy for EC in place in relation to smaller projects and clients, interviewee 4: ‘I would say the larger the project the easier because typically with all of these projects we have had a carbon consultant involved who has assisted with the calculations, so the larger the project the more likely that the client will have a fee that they can pay to a carbon consultant. If it is a very small project, chances are that you wouldn’t really be able to add a consultant for something so specialist’. Considering all the above, clients were found to be the most influential parameter of a project as they set up the contractual agreements, carbon policies and carbon consultant appointment for the projects.

At the moment sustainability in projects is mostly driven by BREEAM rating achievement ambition and Part L regulations and therefore mostly focuses on OC, interviewee 4: ‘most of sustainability decisions that are made are based around BREEAM requirements, planning requirements and still most of the energy and sustainability work is done in terms of OE and part L regulations’. EC calculations at the moment are rare and are most commonly performed after the completion of the project as an after exercise and very rarely play part of the building design process, interviewee 3: ‘Most of my work at the moment has come thorough retrospective review’. When they do take part of the design considerations and they are included in the brief as a target, they have equal priority with the other sustainability targets by the design team, interviewee 4: ‘You have to meet all of the criteria that are included in the targets, there is no priority’. However, since it has no regulatory impact, it often doesn’t get the same priority by the clients; interviewee 4: ‘I would say that if something has a specific cost implication, that is more likely to be value engineered out than something else. But that is usually a client issue rather than an architect issue.’

Early engagement of sustainability consultants with the design team was considered critical by the LCA and sustainability consultants that participated in the interviews (interviewees 1, 2 and 3). They suggested that their engagement should start at least from concept design, with one interviewee stating that the ideal would be as early as site selection of the project, interviewee 1: ‘it is very important to get there as early as possible. Some of the recommendations could be relevant to the building site selection’. Apart from early engagement of the carbon/ sustainability consultant, it was also deemed important that the contractor and the main suppliers also become involved early on so that they can all work collectively towards the carbon reduction targets, interviewee 2: ‘bringing in the main contractor but also tendering contractors or suppliers like sub-contractors from early on in the design process in order to engage with them at an early stage, [...]. And then working side by side and hand in hand with the entire team’.

**EC information exchanges and sources**

EC information exchanges were investigated in terms of when EC considerations are introduced to the design, the professionals involved in the information exchange for EC calculations and the sources of information used for its calculation.

In terms of when EC considerations are introduced, interviewees 1 and 3 mentioned that this would not be during the design stage but rather during or after the construction phase, interviewee 1: ‘It is usually fairly late, at the end of when the building is built or during construction. I don’t think I have ever gotten involved at the design stage’, interviewee 3: ‘Most of my work at the moment has come thorough retrospective review’. For projects that include EC into design considerations, this would most commonly happen at the end of developed design stage or even at the end of technical design stage when the design has entered a more detailed phase, interviewee 4: ‘I think that for most projects in the industry it
would be at the end of Stage 3 maybe or even at the end of Stage 4’. However, it was mentioned that for projects with high sustainability aspirations, EC considerations would start from concept design, interviewee 2: ‘So if it is a project that has high environmental aspirations we would get involved fairly early, around later than concept design RIBA Stage 2’. The stages mentioned above relate to building stages as defined by the Royal Institute of British Architects (RIBA) in their Plan of works document, Figure 1. According to the RIBA plan of works green overlay, Stage 2 is the recommended stage for EC considerations to be introduced (Royal Institute of British Architects 2011).

![Figure 1 RIBA project stages (Royal Institution of British Architects 2013).](image)

The professionals who perform the carbon calculations are most commonly carbon/sustainability consultants appointed by the client. The professionals who are involved in the information exchange process are initially the architects and the design team that provide material information and specifications. This is then either directly communicated with the carbon consultant, or with the cost consultant/quantity surveyor who gathers material quantity information and communicates it to the carbon/sustainability consultant. In cases where this process is completed after the project is built, the design team may not still be available, so the carbon consultant gather the information from the main contractor in the form of drawings. Section drawings have been found very useful as they provide material thicknesses.

The boundary conditions considered were cradle to construction at a minimum but most commonly the boundary condition considered by the interviewees was cradle to grave, which is the boundary condition required for the Royal Institute of Chartered Surveyors (RICS) new professional statement document. This professional statement document provides members with mandatory calculation and reporting requirements about whole life cycle assessment of buildings based on the EN 15978 standard principles (Royal Institution of Chartered Surveyors 2017). With regards to EC data sources, the professionals used independent EC databases or databases that related to specific EC calculation tools as well as Environmental Product Declarations (EPDs).

**Challenges in including EC in building design**

Current UK building legislation on conservation of fuel and power (Part L) and BREEAM 2014¹, focus heavily on OC. This has led to lack of knowledge and understanding of the overall carbon building impact by the building professionals; interviewee 3: ‘If you ask how sustainable your building is they will talk about energy and renewables, not other aspects of building design’. This lack of legislation for EC requirements also creates a lack of a market drive for the industry to start considering it, interviewee 4: ‘Essentially there isn’t a market driver for EC so the people that are doing it tend to be either for their own ambition or as part of a sustainability policy but that usually means that any specific targets can be eased slightly if

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¹ BREEAM is the most commonly used building rating system in the UK and version 2014 is what the industry has been using in the last four years. A new version of BREEAM replaced the 2014 version in March 2018, hence the new version has very recently been introduced to the industry.
need because there is no outside independent review’. This this lack of market drive and knowledge has resulted in limited expertise within the construction industry professionals for EC calculations, interviewee 3: ‘There aren’t many people that do LCA at the moment, there is very little guidance as to what you should do and there is a big risk that people that are actually doing it are doing it completely incorrectly’. Further to this, there is lack of training and a scheme to certify professionals, interviewee 3: ‘The emphasis is on lack of training, if you look at energy related work, other (professional) bodies have a method to becoming an expert to it for information to be compliant. That is the missing step I think with LCA. Until you have a badge though, to specify certified training to get it, you are not sure.’

The main challenge that all interview participants found with EC calculations was the lack of accuracy in secondary data available in EC databases when primary data for the building materials is not available, interviewee 1: ‘You can only get so much primary data from the client and the supply chain, so a lot of the lifecycle has to be filled in with secondary data’, ‘Secondary data are then used to fill the gaps with variant degrees of quality’. In the UK, it was mentioned that the IMPACT database which is linked to the BREEAM standard doesn’t include specific product data but averaged data for products available in the UK. Distances used for the calculations also use averaged UK assumed values. The methodology for the EC calculations was found to be straight forward by most of the respondents apart from one who found that the current guidance only provides a ‘checklist’ rather than a detailed method, interviewee 3: ‘how do you know what is right and what is wrong? It is a checklist but not a detailed method’.

Another challenge mentioned that related to uncertainty was the change of materials from design to what is actually getting built. It was found that there is lack of material specification by the design team which results in uncertainty as to what the end material used will actually be ‘So if an architect puts in a specifications for a system there is little room for deviation. But what normally happens though that it is either a generic statement or it will be we will specify a system, or similar, or approved and that gives the contractor flexibility as to what to install’. Further to this, even when materials are given specifications by the design team, if the project carbon target relates to an overall carbon figure for the entire building, which is often the case, then contractors still have flexibility to change the design team’s specified material if they manage to achieve the building’s overall carbon target by reducing the carbon impact of another element.

Finally an important challenge was found to be the lack of integration of the carbon consultant within the design team ‘estabishing the role of carbon assessment where the whole life environmental assessment is integrated and works side by side. The soft side is very important rather than just the technical one. It is important to stay integrated and to ensure that you are in touch with the project progress and it’s not just an assessment that just happens and is carried out by an external body and there is no interaction whatsoever’, ‘I attend meetings to be present and see how design is progressing. And I am in a position to know what they are talking about. If you don’t do that you may miss it, it is very easy for design to ‘run away’. You could miss a process to evaluate and work with the engineer to report on it. So you need to be mindful to when decisions are made and you need to be embedded in the project team’.

**BIM Application**

BIM application includes both the use of technology and a use of a BIM model but also introduces a procedural change in the construction industry as it facilitates project whole life
cycle data management (Succar 2009; Shrivastava and Chini 2012). The UK Government has mandated collaborative 3D BIM (BIM Level 2) for all public sector projects from 2016 (HM Government 2012). This has resulted in most buildings currently being at that BIM level, however as stated by one of the interview respondents, interviewee 3: ‘There is a variety of levels within level 2 and that really comes down to what do you need it (BIM) for.’

It was mentioned that there is ambiguity and lack of standardisation about the BIM model requirements included in the BIM Protocol, interviewee 3: ‘the key question is what is the expectation of the client - that tends to be the driver’. This was confirmed by another respondent who mentioned that the EC requirements that get included in the Employer Information Requirements (EIR) document come from the client, however, it is the design team that puts the EIR document together, and this is not done until RIBA Stage 2-3. Although the EIR was mentioned to include EC requirements, these only usually relate to an overall building carbon figure and don’t relate to information required within the BIM model; interviewee 4: ‘Our clients aren’t interested in the EC of specific components they are interested in the building they’ll be interested in the analysis and a final number, which may be included in the EIR but it wouldn’t be part of the model’. Further to this, since the cost consultants are usually involved in the EC information exchange process, it was mentioned that pdf documents were used for EC information by the cost consultants rather than the BIM model due to lack of familiarity with BIM data. Only one respondent mentioned that they try to establish a link between BIM and the EC information collection process, interviewee 2: ‘We are trying to interrelate interlink and interact and to have an interface between carbon and BIM and see how they can work together and how BIM can be utilised to extract data that would feed into the carbon calculated process in a streamlined fashion that would facilitate automation.’ Although this was mentioned as a future intention, this is not current practice, interviewee 2: ‘BIM is very catchy and has a lot of potential but whether it is able to what you want is a different story.’

One of the respondents mentioned that one problem encountered in BIM models is that they include building block elements that are not broken down into specific materials, interviewee 3: ‘BIM models have an arbitrary volume that is just a block. So with LCA it is not the block, it is the materials that create this block element that you need information for. So at the moment we have an industry that uses this BIM model that 9 out of 10 doesn’t split down these individual materials of the block elements’. The importance of the right information in the BIM model in relation to metal materials was also highlighted, interviewee 3: ‘So if you take the BIM analogy, the area of your external wall, then you are massively overestimating the volume of metal which is not true.’ Although structural frames are ordered in kilograms and therefore the weight information is easily available, secondary support system metal weight information is not available. The respondent believed that the BIM model can’t be trusted to automatically populate quantity information required for EC calculations, interviewee 3: ‘I don’t trust the BIM model, I like to manually understand what my volumes, my areas my weights I can trust the section drawing, what I don’t trust is the BIM model to automatically populate all these items, I know some aspects are volumes and not the materials in it’. Concern was expressed that with BREEAM 2018, more people will start using the BIM model as an EC information resource, interviewee 3: ‘people won’t have the time to even consider that, they will take a BIM model because they are told to, BIM is telling me that and they’ll put it through. That’s my biggest worry that there’s going to be a lot of information coming through that is going to be completely spurious not through anyone’s
fault.’ It was also stated that there is no checking mechanism for the BIM model inputs or the supporting documentation for the assessments, there is only checking of the final figure.

**BIM potential to facilitate EC inclusion to building design**

All respondents saw potential in BIM facilitating EC inclusion in building design. Two respondents based their opinion on the BIM model's ability to store EC data and material quantities within the model which could feed into the EC calculation process resulting in automation and enabling an iterative process for EC reduction of building designs, interviewee 4: ‘With the BIM model you have all of the quantities and you could in theory have a database inputted in a parameter and you can automatically get a calculation out of that and you can get very quick iterative processes’, interviewee 2: ‘it could help at early stage iterations when you have more generic figures attached to certain components and look at a few major variants to form the design’. One respondent added that this could also enable visualisation of EC results and better communication of these results with clients, interviewee 2: ‘this could add to visualisation and communication with the clients’. Apart from automation of the EC calculation process, one respondent added that the EC data input in the BIM model could also be facilitated by technology, in the form of an application which would simplify the data input process, interviewee 1: ‘Perhaps software can be related to data collection to make it as easy as possible’.

Although three of the respondents focused on the technological side of BIM in terms of its potential to facilitate the inclusion of EC in building design (interviewees 1, 2 and 4), none referred to the information management that BIM contractual documents aim to facilitate. In relation to information management, one of the respondents mentioned the following; interviewee 4: ‘current process is fine, it is not that a complicated a methodology it is more about speeding it up and getting better accuracy’. On the other hand, one of the respondents mentioned the software currently available has a lot more potential, but the data input from the practitioners is what requires improvement, interviewee 3: ‘I think that the software is there and is very very good, I think it is the front end which is lacking.’

**EC growing importance**

All of the respondents acknowledged the growing importance of EC in the overall carbon impact of buildings. They all believed that although there is currently no legislation relating to EC and the market isn’t currently ready to have specific regulatory targets relating to EC, in the coming years there will be regulations put into place, with opinions ranging that this will be introduced in 3-20 years’ time, interviewee 2: ‘I think that is not too far off, within a frame of 3-5 years’ time we will be seeing regulations in some form’, interviewee 1: ‘I am sure it will get to a stage, I don’t think it’s soon, in 15 20 years that we will start seeing some EC legislation’. At the moment even in the lack of a top down approach, the market is attempting to raise their competitiveness by producing EPDs for their products; interviewee 1: ‘a lot being done on individual product level and on EPDs to communicate their impact against their competitors and in the hope that this will get picked up by the procurement team’, but also professionals are raising their competitiveness by adding EC considerations in their project delivery; interviewee 2: ‘Contractors are doing it to a degree for their own sake and corporate responsibility as well which also adds to their marketability from a commercial perspective [...’]. Another aspect of the reason why professionals are voluntarily shifting their focus and try to include EC is for ensuring that projects are going to be meeting future requirements; interviewee 2: ‘it is also about security futureproofing against future regulations and against
resources, the continuously depleting resources that make resource efficiency more and more important’. Interviewee 3 also highlighted that the growing importance of EC is also acknowledged in the new version of BREEAM, which states that EC is increasingly important in terms of reducing the overall emissions that lead to climate change (BRE 2017).

Conclusions and further research

In this paper the results of the initial data collection of this research have been presented which included interviews with construction industry professionals and looked at the role of EC in design and methods for its calculation, the challenges that professionals face in the process as well as BIM application and potential in relation to EC reduction considerations.

The role of EC was found to be mostly dependent on the client aspirations whereas the type of procurement route and type of project didn’t play an important part in the role of EC in design. Larger clients/developers are more commonly the ones with high EC reduction aspirations however at the moment the role of EC is still very small in relation to OC and it is very rarely considered at an early design stage. However, early engagement of the EC consultants with the project, which was suggested to start during concept design was considered critical and it was suggested that all the professionals involved should come together from as early as possible to work collectively towards the carbon reduction targets.

Team integration was one of the challenges identified by the professionals in relation to EC considerations. Lack of EC legislation also brought challenges that relate EC which is a lack of market drive and lack of available expertise and knowledge. There is also no certification and training for EC calculations and this raises uncertainty for professionals who perform EC calculations. Another challenge mentioned was the poor accuracy of secondary data that is included in EC databases. Finally it was highlighted that materials may change from design to construction which is due to either lack of specification set by the design team or because of the flexibility the contractors have if the carbon target is set for the overall building and not the individual component of each element. This again, comes down to the client and what has been agreed within the contract, it is therefore important to incentivise clients and drive the market so that more specific requirements are set to the construction industry by clients.

The new BREEAM version and other available guidance and initiatives like the London Planning policy include EC considerations and that is helping to get the market ready for potential future EC regulations (BRE 2017; Greater London Authority 2017). Even though the EC requirements set by the new BREEAM version were considered limited by the interview respondents, they were found to provide a stepping stone for both building professionals and clients to raise their EC reduction target ambition.

In relation to BIM, professionals found that most of the industry has reached level 2, which is the level that the UK Government has mandated for public buildings, but there is still no standardisation in BIM processes and data input in the BIM model. Although most professionals believed that BIM’s potential to facilitate EC considerations lie within the BIM model’s capability to enable automation of the EC calculation process and better communication of EC results through visualisation, there was also the reluctance to trust the BIM model due to the lack of standardisation and the variation of the data that is inputted in the model. Therefore, in order for the BIM model to become a tool that can be used for facilitation of the EC process, better data input to the BIM model is required. This effectively needs to be set within the contractual agreements that BIM entails, such as the BIM Protocol and the EIR document.
The above conclusions were drawn from a small sample of participants, which included 2 LCA consultants, 1 Sustainability consultant and 1 architect, 4 practitioners in total. Therefore, the above results can’t be generalised to be considered as representative of the UK construction industry. The conclusions from this research form a preliminary part of a wider study which investigates the design process in relation to BIM and how its application can facilitate the inclusion of EEC in design considerations. This study takes an ethnographic approach which includes in-progress building design observation through the immersion of the researcher in the field. Three projects during design stage are included as case studies where the design process is investigated in relation to EC and BIM. Through interviews with the professionals involved in the projects, project meeting observation and document analysis, this research investigates BIM application in relation to EC information during design.
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Chapter Two: Education for sustainability
Integrating Energy Performance Assessment Tools in Architectural Design Studio Education

Mahmoud Mohamadin, Ahmed Abouaiana and Yasser Sakr

Abstract:
Contemporary architects rely on various digital and information technology tools starting from early design stages to construction and manufacturing stages. All these tools are reshaping our approach to architectural design, and consequently, to architectural education. As the environmental issues raise in our current approach to architectural design, available technologies are employed to solve these issues in every possible way. Departing from this point of view, energy performance assessment (EPA) tools seem to be useful in the architectural design pedagogy as it affects major design decisions and may completely alter the design process itself. The aim of this paper is to investigate empirically the potential of employing EPA tools in architectural design studio education with the focus on its impact on the design process. A workshop study was held in the design studios of the second year of the department of Architecture at the faculty of Fine Arts, Helwan University, Cairo, Egypt. A number of thirty six students were selected from the three studios of the department out of the total of hundred ninety eight students to participate in the study as an experimental group. Evaluation of the validity of this study was based on the students’ feedback on the experiment through short structured questionnaire, and semi-structured interviews either individually, or in groups. The students of the experimental group could make better judgements on the environmental aspects in their design process. This confirms the applicability of the integration of EPA tools in architectural design studio education to enhance the understanding of the knowledge gained in environmental design projects. Furthermore, this study can help mapping out strategic recommendations for further studies for a model of implementing such tools in the design studio pedagogy.

Keywords: architectural education, design studio, energy performance assessment (EPA), ICT.

Introduction

ICT has been evolving dramatically in the recent decade, which lead to radical development in Architecture, Engineering & Construction (AEC) sector. In particular, computer software tools which are used in design process such as Computer-Aided Design (CAD) and Building Information Modelling (BIM) (Moum, 2006) and (Penttilä, 2007) are being considered as a real expression of ICT in the field. These tools are identified in terms of their profound benefits (Khodeir, and Nessim, 2017) not only for competitiveness among architectural firms, but also for their influence on people’s life by reducing energy consumption to respond to the rapid increase on energy demand where buildings’ sector are responsible for about 40% of energy consumption (European Commission. 2017).

Therefore, BIM and EPA go hand in hand as EPA plays an essential role to enhance environmental performance of buildings using its capability to optimize energy consumption in conceptual design stage (Schlueter, A. and Geyer, P., 2018). Energy Plus simulation engine could be taken as an example, (Pagani & Chiesa, 2017) illustrate, as shown in Figure 1, the link between Energy Plus engine, and BIM most used platform Revit.
Previous studies investigated the implications of the use of performance simulation tools in early design stage in practice (Attia, Gratia, De Herde, & Hensen, 2012) and (Castro & Alvarado, 2017) and others. It is rather important that in architectural education, the most rudimental step which prepares architects for the near future, thus raising awareness of students in terms of energy efficient designs, in addition to push their capabilities of using simulation tools up from the beginning of design process. Integration of EPA tools in architectural education has already been adopted in several educational institutions (Nault, Moreno, Rey, and Andersen, 2017) yet the researchers concluded from the available litterateur that it is still limited to the environmental labs, and its application is not yet sufficiently extended to the design studio. This means that the students learn the use of these tools only for optimisation of spaces, or micro-climates after the design decision making stage. Unlike these practices, this study focuses on the potential of implementing these tools in early design stages, and its implications on the design process in terms of form, and tectonics.

Methodology

Due to the student-centered approach intended in this study, ethnographic research method was adopted, where the researchers observe and interact with the study’s participants in their real-life environment for the purpose of enabling them to understand as much as possible about the study population (Balsiger & Lambelet, 2014). The study was implemented on a case study in the design studio of the second year at the department of Architecture at the faculty of Fine Arts, Helwan University, Cairo, Egypt. The study took the form of a workshop, where a number of thirty six students were selected from the three studios of the department to participate in the study as an experimental group. They represented the three formal design studios that contained a total number of students of hundred ninety eight. Participants were gathered in one design studio setting upon a request arranged with the responsible professors of the three studios. The students were told that participation in the study was not obligatory, and that it would not affect their evaluation throughout the course.

The researchers limited the study’s application to Autodesk FormIt platform, an architectural modelling software for architects to sketch, collaborate, analyse and revise early-stage design concepts. It allows users to create architectural modelling for tablet, web, and windows, and it has the ability to design with intelligence by connecting to other Autodesk apps to conduct an early analysis of space, energy and solar (“Autodesk FormIt”),
in addition to other differentiators that we are not taking into our consideration in this study.

Since all EPA tools are based on 3D digital modelling, experimental group pre-selection criterion was based on the student basic knowledge of 3D digital modelling software. Additionally, other factors were taken into consideration; (i) Express of interest of the student, (ii) Distribution of the selected students on the three studios of the department as follows: from studio 1, 12 selected out of 67, from studio 2, 16 selected out of 68, and studio 3, 8 selected out of 69 as shown in (Annex 2).

The experimental group had a brief introduction to the software, and a quick training for one week to ensure they understand how to start to apply it on their projects, while the rest of the students were left to work on the project with the ordinary help and guidance of their tutors, but without the help of any simulation tool.

The term architectural design process means a methodological series of steps that comprise data collection, conceptualization, schematic design, design development, and execution design documents. The workshop focused on the schematic design phase of the project, specifically the phase so called form generation phase. Each one of the participating students in the experimental group was asked to conduct the necessary simulations on the building forms they propose using Autodesk FormIt software until they reach an optimal composition in terms of sun exposure, and shadow on masses. The students were then encouraged to try to make their design decisions based on the simulation results either in form generation, or in façade treatment.

A short structured questionnaire on environmental performance assessment tools was designed, and it was distributed in the beginning, and at the end of the project on the experimental group in order to measure their awareness level of these tools, and to investigate if there was any significant differences. Semi-structured interviews took place as well to discuss the students’ feedback on the experiences they gained through the workshop, and how this influenced their way in thinking and acting towards environmental design processes.

The Project

The project held in these design studios was assigned by the teaching staff. It was a residential villa for an artist; musician, painter, or sculptor ... etc, and it was located in a coastal area with a waterfront in the North direction. The building shouldn't have exceeded three stories, and the architectural program consisted of the following spaces: Villa reception halls, kitchen, guest toilet, two bedrooms with bathroom, master bedroom with private bathroom, family living space, and finally, an atelier for the artist. The form generation process assigned by the teaching staff was based on the formation, deformation, and transformation of an original geometry of a cube with the dimensions of 12m X 12m X 12m. The students were asked to conduct trials for the form generation that may include, but not limited to; addition, subtraction, subdivision, cracking, rotation, shifting, stacking, layering, or twisting, until they would reach a form composition that corresponds to both the functional requirements, as well as the contextual constraints, figure 2 depicts some samples of students work before the interventions.
This design process that is based on the formation and superimposition of masses seemed to be going in line with the proposed hypothesis of this study. For instance, it gave the possibility of integrating the solar analysis of Autodesk FormIt software in the form generation process, which affected the design decisions made by the students in this phase. Students could apply modifications to the form to ameliorate it in terms of its relationship with the sun path around the masses, building faces exposure to the sun, and shade and shadow on building façades according to the results of the solar analysis that gave a better understanding of these considerations.

**The Intervention**

The workshop took place on weekly basis, with two sessions each week, and in a total of four sessions. The research team started its intervention to the project with an introductory lecture on Autodesk FormIt software and its instructions. Purpose, aim, and objectives of the workshop were discussed, the work plan throughout the workshop timeline was handed out, and the selection of the participant students was done. Participant students were given instructions on the program installation, tutorials, and resources.

The second session was an in-class training on the detailed instructions to use FormIt software either for 3D modelling, or for solar analysis. Figure 3 illustrates examples of the students’ 3D FormIt models.

![Figure 3. Examples of the students’ FormIt models.](image)

The third session comprised a lecture regarding the following considerations; Firstly, the role of material’s thermal transmittance (U-Value) for both of opaque and transparent parts of building envelope. Secondly, window to wall ratio (WWR). Thirdly, creating shading through using simple shading devices and massing. Eventually, the role of orientation of spaces. Then the time left was dedicated to the form generation process.

Each student, using Autodesk FormIt, created his/her initial form previously prepared during their course in the design studio. The aim of this phase was to apply the solar analysis on the form composition and explore the relations, and implications of the sun on the building different façades, highlighting the relationship between the
environmental forces and building form generation. In this phase, students were asked to reflect on the results of the simulation, the problems they have encountered, and their suggestions toward improvements of such implications.

This lead to the application of some modifications to the preliminary form in an ongoing process between simulation and modification. This is exactly what we can call the simulation-based form generation process, Figure 4 shows an example of projects where form has been generated due to environmental aspects.

![Figure 4. Two examples of students' projects.](image)

The fourth and last session was a follow up session to explore more adjustments to the design according to the functional and contextual forces, and recommendations for the skin and roof treatments. Table 1 summarizes the work plan in Annex 1.

**Discussion Of Results**

A short structured questionnaire was distributed on the experimental group through the online platform of Google forms. Students’ attention was drawn to the fact that the questions were not exclusive and we’re used to help them reflect on what environmental considerations may comprise. It consisted of three questions on whether the student knows or not the worst orientation for buildings in Egypt (figure 5), the height of the sun inclination angle in summer and winter (figure 6), and lastly, whether the student have ever used EPA tools before (figure 7). Nineteen students out of thirty six students responded to the questionnaire. The results of the questionnaire are shown in the following figures.

![Figure 5. Response of solar latitude angle height](image)

![Figure 6. Response of orientation](image)

![Figure 7. Response of using EPA tools](image)

Figure 5 depicts that fifteen students are aware enough that the solar latitude angle in summer is higher than in winter, while figure 6 shows that more than of half of the sample selected southern orientation as the worst façade orientation in Egypt, twelve students chose southwest, three students chose west, south east and north were selected by one student for each, and finally, one students said that “There is not a worst standard
orientation. It depends on space’s function and uses”. Eventually figure 7. Illustrates that all of the sample group except one student have never used EPA tools before. The results of the study showed some interesting findings on the students’ approach to architectural design before and after the experiment.

The attendance throughout the four sessions accounted by an average of 75% to 90% Since the study was conducted on a case study of sophomore architectural students, a lack of environmental competencies was normally expected to show up, and it was noticed that by the end of the workshop the students of the experimental group expressed their satisfaction of the new competencies gained from it, and how it was relatively easier for them to understand these aspects.

Semi-structured interviews were held with the students during and in the end of the workshop. It is worth mentioning that the intervention started in a late phase of the project’s design stage, which left a very limited time for the workshop to be conducted, therefore, and another round of interviews was held after the end of the semester in July 2018. Some interesting comments raised up during the interviews and discussions with the students about their feedback on the experiment. After having encountered the integrated approach of using solar analysis as a design support tool, and after having obtained the results of the simulations conducted on the masses of their projects, some of the students stated that they decided to make a critical decision of not only applying modifications, but to completely change their mass composition to effectively respond to these environmental considerations.

Mainly, the comments of the majority of the students were about the knowledge gained from this experience. These are such as; the importance of buildings orientation and that the correct choice of façades orientation, which is not a constant decision in all situations, but it depends on several considerations, thus building location, and function of spaces.

Another important point highlighted by the students was the possibility of using solar analysis simulations to conduct numerous trials in a relatively short time to choose an optimal mass composition in terms of solar exposure, and shade and shadows. In addition, some students commented on the usefulness of taking into consideration the environmental aspects in such an early stage of the design process where decisions could be crucial and could lead to major changes in the design output. However, two students out of the 36 participants were neutral regarding any advantages from this workshop.

Conclusion

In conclusion, ICT showed its effectiveness in all the architectural process so far starting from data collection to construction and fabrication. As investigated from litterateur, EPA tools can play a crucial role in early design stages as a decision support tool in architectural practice, and this has been confirmed in this study on the educational level. The study showed that even in a context of sophomore students environmental competencies can be enhanced remarkably using simple, yet effective EPA tools in the design studio. The study pays the attention to the fact that implementing these tools in the design studio of sophomore students is extendable to senior level students, but the researchers argue that this integration can face difficulties if applied on a freshman students level due to the lack of knowledge regarding this subject of matter.
Authors Contributions

Energy Performance Assessment Tools in Architectural Design: (Abouaiana, A)
Architectural Design Studio Education: (Mohamadin, M.)
Empirical Study: (Research Team)

Acknowledgement

The research team thanks Prof. Dr. Amal Ahmed Abdou, the head of Architecture Department, and all the teaching staff of the second year of Architecture at the faculty of Fine Arts, Helwan University in Cairo, Egypt, for giving the opportunity to implement this study within their design studios.

References


(Annex A) Table 1. Work plan for integrating EPA tools in the design studio.

<table>
<thead>
<tr>
<th>Session / Date</th>
<th>Teaching Activity</th>
<th>Content</th>
</tr>
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<tbody>
<tr>
<td>Session 1 / Week 1: Monday, November 27, 2017</td>
<td>Introductory Lecture</td>
<td>Research team introduction. Study purpose, aim, and objectives. Work plan throughout the course timeline. Introduction to FormIt software, tutorials and resources, and program installation. Selection of participants.</td>
</tr>
<tr>
<td>Session 2 / Week 1: Wednesday, November 29, 2017</td>
<td>Lecture on FormIt in-class training session</td>
<td>Detailed instructions to use FormIt software: 3D modelling. Energy Assessment.</td>
</tr>
<tr>
<td>Session 3 / Week 2: Monday, December 4, and Wednesday, December 6, 2017</td>
<td>Form generation in-class work sessions</td>
<td>Highlighting the relationship between the environmental forces and building form generation.</td>
</tr>
<tr>
<td>Session 4 / Week 2: Monday, December 4, and Wednesday, December 6, 2017</td>
<td>Design development</td>
<td>Follow up sessions. Design adjustment according to the functional and contextual forces. Skin and roof treatments Plans, and sections.</td>
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(Annex B) Tables 2&3. Experimental group participants.
<table>
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<tr>
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<tr>
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<td>Salma Ahmed</td>
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<td>Sara Gamal</td>
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<td>Virona Ihab</td>
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<td>Ucif Mohamed</td>
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<td>Walaa Yassin</td>
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<td>Wessam Saud</td>
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<td>Yasmeen Raffat</td>
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<td>Yasmeen Mostafa</td>
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<td>Youstina Ashraf</td>
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Towards an Ecological Architectural Education in Kuwait

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Abstract: Kuwait has been increasingly experiencing rapid changes in its constructed environment, affecting in its way its natural environment and ecosystem. With the plans for “New Kuwait” and the continued development of mega projects in the region, architectural education has an integral role to play in changing the current practices and discourse concerning the new and existing. This paper provides insights into the means in which multi- and cross disciplinary approaches that consciously engage proactive ecological principles and methods in urban and architectural designs can be implemented: firstly, through a critique supported by existing theories and discourse; and secondly, using Kuwait’s Free Trade Zone area in Shuwaikh as a case study. The paper alludes that the desert landscape can no longer be viewed as a “tabula rasa” for urban development but a delicate ecosystem with high ecological value. Additionally, the paper provides the argument that smaller scale tactile urban and architectural interventions can aid the move towards a way of sustainability that is resilient for combating the challenges we will face in the future projected changes in the climate. The story of the conventional ways of new construction in Kuwait that has been supported and encouraged by the public and private sectors since the 1950s needs to change to consider the current environmental challenges to pave way for a kind of sustainable development that is beneficial for all.

Keywords: Architectural Education, Landscape Urbanism, Ecological Sustainability, Critical Thinking, Kuwait

Introduction

‘When distance and convenience sets in; the small, the various and the personal wither away.’ — Jane Jacobs, (The Death and Life of Great American Cities)

A 2017 report by the Global Finance Magazine, data gathered by the International Monetary Fund, ranked Kuwait sixth in GDP at a soaring $71,263 purchasing power parity (ppp) per capita. Yet unlike most of its western rivals, Kuwait along with its sister oil-rich Gulf States underwent different development paradigms. Since its independence in 1961, Kuwait, as a sovereign state, has already undergone rapid changes in its built environment. Owed to the discovery of large oil reserves in the region, Kuwait along with its neighbouring high-income developing nations bypassed the processes of industrialisation and were propelled into the 20th century. Most of the built fabric that shaped the vernacular city in the pre-oil era (a dense aggregation of introverted mud houses arranged around a central courtyard, separated by narrow sun-shielding alleyways locally referred to as a Sikka) was demolished to pave way for urban typologies and archetypes that conform to Western modernist architectural and planning ideals and principles.

Kuwait’s built landscape today is almost entirely devoid of its vernacular past and consists largely of new construction realised in the past 60 years. The move to modernity has resulted in the fragmentation of urban life and removed the past’s level of intimacy and engagements with the surroundings, the type of engagement urbanists Jane Jacobs advocated for since the 1960s.

Moreover, the current urban systems consume enormous amounts of energy and resources, thereby generating vast amounts of pollution and waste. Kuwait is one of the highest per capita waste generating nations in the world (Brinkmann and Garren, 2018). It is driven by the country’s persistent aim for economic growth that embraces the continual of
urbanisation (Fig. 1) and consumerism in an unsustainable manner supported by built and infrastructural interventions.

Lack of comprehensive planning visions and loose implementation of urban policies, coupled with current environmental ethics in Kuwait, or lack thereof, continues to disrupt ecosystems with detrimental consequences to the bios, “bare life” as Agamben (1995) coins it. This is in part due to sea water pollution, air pollution, groundwater contamination, toxic gases emissions, and unregulated fires (Kuwait Times, 2018; Country Watch, 2018). Without change in behaviours, this type of continued engagements will lead to catastrophic results, affecting all scales from local to regional.

The interconnected nature of the situation is consequently begging for multi- and cross disciplinary approaches that consciously engage proactive ecological principles and methods in urban and architectural designs. This type of engagement is where practices in Kuwait are fundamentally lagging behind today. This paper as a result provides insights into the means in which changes towards ecological understandings can be achieved firstly, through a critique supported by the existing theories and discourse, and secondly, using the Kuwait Free Trade Zone area in Shuwaikh as a case study. The main argument in this paper is that architectural education has an integral role to play in changing the current mind-sets of understandings, discourse and ways of (re)designing the existing and new. Incorporating more holistic ecological principles in architectural education will empower the new generations of architects and designers to better engage with their environments. Additionally, they will be more capable and prepared to comprehend and create interventions that address the current and future environmental challenges in Kuwait and the region.

Critical Regionalism and the Constructed Environment in Modern Kuwait

Regionally throughout cultures in ancient times there was stronger connection between nature and the built form. Examples from the Hanging Gardens of Babylon to the earthen beehive houses in the Levantine region show us that in the past there existed a level of sensitivity in the understandings of the local ecological and human needs. Living was not alienated from the outdoors and in part due to the limited technology was integral component of the built forms and interiors.
The natural constituted an integral discursive mode in philosophical discourse and the everyday life. Examples can be found in the numerous literature and scriptures such as in Sufi writings. The Epic of Gilgamesh provides the earliest dated literature and example of an environmental awareness, narrating how the fertile crescent of Mesopotamia, upon which thrived the ancient Sumerian civilization circa 4000 BC, has fallen dry and become the arid, barren desert-landscape of modern-day Iraq (Hartmann, 1999). The morale behind the writings fundamentally asserts that the action of tampering with the natural environment may result in irreversible consequences with catastrophic implications on all forms of life, human and non-human.

The ecological impacts of the industrial revolution that swept the Western Hemisphere from the mid-18th century, and manifested over the following two hundred years are still imminent; their repercussions felt at a global scale today. The realisation of its detrimental effect on living beings and the environment was initially raised in Rachel Carsten’s “Silent Spring” in 1962, a year after Kuwait’s independence. While Kuwait was preparing for change since the initial discovery of oil in February 1938, its full impact was more realised later in the 1960s. The writings of Saba Shiber provide many glimpses of the sudden changes that were happening from infrastructural to local’s behaviours.

He includes that the pre-oil residents of the old city of Kuwait were skilful in craftsmanship that extended to shaping their built environment. Shiber states in his seminal book “The Kuwait Urbanisation” that Kuwait ‘produced a dignified, indigenous architecture without architects’ (Shiber, 1964:p.310). Past architectural elements such as walls were created for structural function to provide stability and natural insulation from heat during the harsh summer seasons (Al-Bahar, 1984; Shiber, 1964). Shiber went further explaining that ‘even the poor elements of society refused to allow money and property to be a dividing factor’ (Shiber, 1964:p.76). The old city safeguarded the embodiment of the quality of modesty, regardless of socioeconomic statuses, that brought with it durability, functional simplicity and beauty, conforming as a result to Vitruvius’s treatise of the 3 principles of good architecture.

Kuwait’s built landscape went through its most transformative phase during the 1930 to 1960s. The transition to modernity has created a nation that is fully dependent to outside sources, as a result ridding the direct relationship that existed between the maker and user and the local environment. Today it is experiencing further decline in behaviours from their previous ancestors by becoming more and more known as the concrete and consumer society. The places that are becoming more and more popular consist mostly of mega projects, such as the Avenues shopping mall and the Sheikh Jaber Al Ahmad and Sheikh Abdullah Al Salem Cultural Centres. In addition, according to the “New Kuwait” 2035 strategy such projects will continue to materialise and grow in the future. New highways and roads are being developed by the Ministry of Public Works and Public Authority for Roads and Transport such as in the Shuwaikh district and the new Nuwaiseeb project along the Nuwaiseeb border with Saudi Arabia, without full consideration of their environmental impacts. None of the new projects are prioritising to tackle the ecological implications and the urgent environmental hazardous situations that are occurring in various already existing parts of Kuwait, such as the polluting and dire situation in Shuwaikh Industrial zone and Shuwaikh residential district, the landfill sites in Sulaibiyah, Kabad, Al-Quairain, Shuaiba, Jleeb Al Shuyoukh, West Yarmouk, and the poor waste planning and management in residential districts, among others.
Therefore, how can ecological and pro-environmental design interventions and planning be implemented in Kuwait? Essentially the environmental challenges Kuwait is facing today cannot only be alleviated through singular (mega) architectural interventions but through a more interconnected cohesive design innovations that incorporate ecological principles of biodiversity, natural life cycle, and so forth. These types of innovations have to start early on during the architectural education and training phases in order to challenge the existing mainstream applications and standards. The story of the conventional ways of new construction in Kuwait has been supported and encouraged by the public and private sectors since the 1950s and this need to change to pave way for a kind of sustainability that is locally beneficial to living beings and the environment.

**The Current Urban and Architectural [Environmental] Interventions in the Region**

Worldwide, sustainably driven causes have aided in the development of knowledge, such as about supply chain management, logistics, toxicity, nutrient recovery, material flows, and many more. When it concerns the construction industry, globally there have been efforts in recent years to the systematic implementation of sustainability through the adoption of green building rating systems. Some of the popular rating systems include Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREAAM), Energy Star, and Green Globe.

The most common building rating system adopted in the Gulf region is LEED green building rating system. Since its launch in 1998, the building rating system has evolved into 4 major categories for certification: LEED for Building Design and Construction, LEED for Interior Design and Construction, LEED for Building Operations and Maintenance, and LEED for neighbourhood Development. The most commonly used in the Gulf region is LEED for Building Design and Construction, which in the past was called LEED for New Construction. LEED-registered buildings have risen across the region, from 623 in 2010 to more than 1400 in 2015 (EcoMENA, 2018).

Some of the prominent green buildings are Masdar Institute of Science and Technology in Masdar City that includes the Siemen’s headquarters, being the first LEED Platinum-rated office building in the entire Middle East, Climate Change Initiative Building in Dubai, Qatar National Convention Centre in Doha, King Abdullah University of Science and Technology (Jeddah) and World Trade Centre in Bahrain. However, there are few that aim to adopt sustainability in more ecological manner. The closest rating system that is adopted regionally that includes the neighbourhood is the LEED for Neighbourhood Development certification. LEED-ND comprises new land development projects or redevelopment projects containing residential uses, non-residential uses, or a mix, and recommends that at least 50% of total building floor area be new construction or major renovation, with buildings within the project and features in the public realm are evaluated (LEED Online, 2018).

Msheireb Downtown Doha is regarded as the world’s first sustainable community in the Gulf region that is implementing the LEED-ND certification, with buildings targeted for LEED Gold and Platinum rating that includes 59 LEED for Building Design and Construction projects, 37 LEED for Homes projects and a LEED Neighbourhood Development project (Gulf Times, 2015). Kuwait is still behind in implementing this type of sustainable mega scale projects, having the neighbourhood development as well the individual entities involved in mind. Currently on the LEED online directory there are 44 projects, majority of which are registered for LEED certification under the New Construction v2009 (Fig. 2). In addition, the
completed architectural projects do not engage in resolving their existing surroundings’ dire situations, some examples of which are mentioned throughout this paper.

As part of the 2035 strategy, Kuwait is currently undergoing plans for “New Kuwait” (KUNA, 2017). The plan embraces reforms through mega projects, including construction and urban developments that are predominantly led by the private sector. As a result, the new has been of greater priority since the early modern urban planning era resulting in the utilitarian value and use of land to be the priority and debate for the continuance of modernisation of Kuwait. Entities in power have been pushing since the 1960s for the act of demolition to continue to make way for newer and newer buildings, infrastructure and roadways, bringing with it the increase in waste and pollution. In addition, Kuwait has become so dependent on the automobile that people are prepared to put up with the eradication of the pavement for parking purposes. The increase in the number of automobiles has caused air pollution (Abdul-Wahab and Al-Arairni, 2004) and disturbances in all aspects of human-environment conditions in the majority of the neighbourhoods in Kuwait. Numerous examples are found through aerial views of Kuwait dominated by scenes of ad hoc open land parking lots and congestion (Fig. 3). This shows that the new is creating a fragmented dissociative landscape.

Figure 2. LEED projects in Kuwait (Data Source: LEED Online 2018, graphed by author Lamis Behbehani).

Figure 3. Aerial view of open land condition in Salmiya (Source: Photograph by author Lamis Behbehani)
Furthermore, the priority in the Gulf is to strive for energy conservation and not for ecological-human wellbeing. This is evident in the plans and activities that are happening and the continued increase and use of the conventional highways and mega commercial projects. Mohsen Mustafavi (2010) includes that:

‘We might consider the impact of the ecological paradigm not only on ourselves and our social actions in relation to the environment, but also on the very methods of thinking that we apply to the development of the disciplines that provide the frameworks for shaping those environments’ (cited in Pollalis et al., 2012: p.329).

A strong attribute of ecological design and thinking is life cycle management and biodiversity. Approaches such as Cradle to Cradle that aim to create intelligent products, processes and systems taking into account the entire life cycle of the product, optimising material health, recyclability, renewable energy use, water efficiency and quality, and social responsibility (McDonough, 2002) and permaculture are still not popular and fully implemented.

**Landscape Urbanism as a Theoretical and Practical Framework**

As academics and educators we often question how architecture can aid in the making, serving and healing of places? As architectural education evolves in Kuwait and the region, greater emphasis on the critical role of landscape is therefore necessary in mitigating the ramifications of urbanisation on local ecologies. It needs to include avenues where interdisciplinary thinking is possible to foster an environmental ethic; one that is critically responsive to the local natural and constructed ecosystems. In a society where there is a semantic barrier in the public psyche as to what the term landscape means, Landscape Urbanism, when applied to the Kuwaiti context, could potentially offer renewed understandings.

Landscape Urbanism is an emergent theory in the Western discourse of landscape that fundamentally aims for the disciplinary reconciliation between architecture, landscape, and planning. It arisen in response to the New Urbanism and views the city as formed by ecological processes rather than a consequence of the modernist vision of the city’s rigid building blocks. Landscape Urbanism promotes using the white space caused by separated buildings to create ‘green systems’ as the foundational structuring element (Kullman, 2015); thereby inverting the conventional reading of figure-ground relationships. Attuned to this vision, Landscape Urbanism in this context presents itself as a practice aimed at combining urban planning with the art of landscape architecture (Morenas, 2012). In other terms, Landscape Urbanism refers to a ‘disciplinary realignment in which landscape supplants architecture’s historical role as the basic building block of urban design’ (Waldheim, 2012:p.37).

Thus far, Landscape Urbanism is an emerging practice with a number of university institutions worldwide advocating its principles in their pedagogies; several design firms mobilizing the term in the scope of their services, and media and press sources publicizing the movement. It is a two-fold approach to urban design: firstly, to consider water management, infrastructure, human activity, biodiversity, and other aspects of the complex urban conditions; and secondly, to study implications of the built city in the landscape as well as the landscape of the city (Gray, 2011). Therefore, Landscape Urbanism stipulates that landscape is a model and framework for urban initiatives and a new perspective on the city. In this respect, the concept of Landscape Urbanism implies a kind of hybridization as
positioned between landscape and architecture to articulate the value of landscape in describing a horizontal alignment of the contemporary city. The doctrine assumes that landscape is the lens to understand the diversity and complexity of modern densely populated cities in the age of raised industrialization, sprawl, and artificial open space (Gray, 2006). Accordingly, the profession of landscape architecture was claimed to be the only solution to the growing environmental crisis. A Declaration of Concern launched in 1966 by Campbell Miller and his supporters in front of Independence Hall in Philadelphia laid the ground for the establishment of the Landscape Architecture Foundation (LAF), which has guided the practice for over 50 years (The Dirt Contributor, 2016).

The principles of Landscape Urbanism require developing sustainable processes to consider the ever-changing nature of the environment, relying on horizontal structuring, using methods and techniques to adjust the city structure to the environment, and boost the imaginary (Melville, 1995). McHarg’s seminal book “Design with Nature” (1969) notions the application of Landscape Urbanism by introducing a framework of landscape planning to embed aesthetics in urban planning. The planning method of McHarg facilitated the dialogue, collaboration, and coordination between ecologists and designers, which are also illustrated in some of his urban projects (Weller, 2008). Another prominent figure in the history of the movement’s growth as both theory and practice is Charles Waldheim, the founder of the scholar community at the University of Illinois, Chicago, one of the current Landscape Urbanism’s strongholds. In his writings and activity, Waldheim has exhibited the potential and complexity of landscape alignment in urban design (M’Closkey, 2008).

However, in the Gulf region and Kuwait for approaches such as Landscape Urbanism to be appreciated and implemented there needs to be shift in understandings by the public and private sectors supported by incentives at various scales. There is an urgent need for appreciation and inclusion of architecture and design professions knowledgeable and specialised in landscapes and ecology in the future plans for sustainable development.

The Constructed Environment and the Future of Architectural Education in Kuwait

Currently, there are no stringent implementations in Kuwait where sustainability of the built environment at urban developmental scale is prioritised. There are limited opportunities where the main stream is currently challenged and this is through one-off public engagements and the academic activities that are taking place at the local universities, museums and cultural centres. Educational institutions have been vocal about issues pertaining to Kuwait from the demolition of pre-oil and modern buildings to the destruction of suburban parks and gardens (Behbehani, 2016; Kuwait Times, 2016; Kuwait Times, 2018).

Kuwait University is the sole institution that offers architectural design education in Kuwait. The College of Architecture at Kuwait University has evolved since its inception in 1997 from just the Department of Architecture by including the additional programs, interior architecture and communication design. This inclusion has allowed for diversity of topics pertaining to environmental issues in Kuwait to be surfaced and addressed by the students and faculty involved. However, it does not still offer specialties in landscape and urban design, nor for interdisciplinary engagements between the departments within the college or outside.

One of the avenues in which interdisciplinary thinking is made possible is through the elective courses that are offered at the College for pushing the students to get familiarised with additional aspects that affect architecture and interiors. However, the approach is
highly dependent on the instructors who cover the electives. Some of these courses include introduction to landscape architecture and special topics in architectural preservation.

By improving understandings and knowledge of urbanism and landscape, and incorporating the principles of landscape urbanism helps to move away from the traditional approach of architectural education (such as functionalism and pure aesthetics) to creating interventions for solving existing and projected environmental challenges through built forms. Mohsen Mostafavi wrote:

‘We need to view the fragility of the planet and its resources as an opportunity for speculative design innovations rather than as a form of technical legitimation for promoting conventional solutions. By extension, the problems confronting our cities and regions would then become opportunities to define a new approach’ (cited in Hagan, 2010: p.9).

Sustainable architecture seeks to minimise the negative impact of the built on the living and natural environments. Additionally, full understanding of the ecosystem and natural environment is even more important in situations of pollution and natural and human-made catastrophes. This is when understandings about the natural landscape become of importance. Although there are Kuwaiti professionals in landscape architecture, the discourse on the discipline is lacking in academia and the public and proper accreditation for practice. The issue is largely semantically rooted with much ambiguity in the definitive meaning of landscape and urban design and their relationships to architecture, especially among the authorities in the public sector in Kuwait. Therefore, with limited information available, acquiring understandings about the natural and constructed landscapes depends on primary sources such as fieldworks and site visits.

The Shuwaikh’s Free Trade Zone Area

The Free Trade Zone area (FTZ) is an area in Kuwait that deserves attention for various reasons. FTZ was established in 1999. It is a 1.5 million square metres area in the port of Shuwaikh, consisting largely of reclaimed land used for trading and shipping containers. Since its establishment and until 2006, the zone has been managed, with agreement signed with the Kuwaiti Government, by the privately owned National Real Estate Company (NREC). It has gone through frequent management and operational disputes, which has had a detrimental impact on the site. Currently, the bay area is contaminated due to the commercial shipping activities and untreated storm water and sewage discharges (Fig.4).

Figure 4. The polluted beachfronts of Shuwaikh’s Free Trade Zone area
(Source: Photograph by author Lamis Behbehani)
Despite of the dire situation this large brownfield site is still being zoned and planned for commercial use. The type of existing functions in and around the FTZ area includes for example, warehouses with storage facilities for rent along with land for development, exhibition spaces, hotels, coffee shops, medical facilities, Kuwait University campus and lodging (Fig. 5).

Through numerous site visits and in groups, students researched and undertook the challenge to remediate the free trade zone in Kuwait for urban and architectural interventions. They employed various means to investigate and understand the site. The collective research and series of proposals by the students tackled environmental, ecological, economic and socio-political issues concerning the past and future of the FTZ. Some of the proposals included redefining the hydrological flow within and around the free trade zone; and bringing back native species and restoring natural ecosystems to the free trade zone through processes of primary and secondary succession (Fig. 6). The scale of the project helped students to explore different aspects of the site and to bring the theoretical knowledge acquired throughout the semester into practice.

These types of investigations aid to view the desert landscape no longer as a “tabula rasa” for urban development but a delicate ecosystem with high ecological value. Built and unbuilt landscapes should be taken as opportunities for innovative interventions that consider human and non-human agents. Such interventions ranging from capitalising on existing abandoned structures and brownfield sites for alternative programs such as seed banking and manipulating coastal topographies to harvest natural remediation systems using algae are a few examples of the core agency of landscape in design. Thus, pushing architectural design to no longer be constricted to attaining a finished static product but
inertly become a process that factors time, both short term tactile interventions as well as long term ones.

**Conclusion**

The role of architecture and construction is continually changing and shaping life in Kuwait. It has moved away from its initial ways of local modest craftsmanship and building. Today Kuwait is highly urbanised and consists of privatised projects orienting towards consumerism and profit. Consequently, this has weakened the local connection between architecture, landscape and ecology.

Alterations to the constructed and natural environments have irreversible implications on both the politically defined local ecosystems delineated by the nation’s geographic borders as well as the regional ecosystems that transcend political boundaries. With the plans towards “New Kuwait” and with the continued development of mega projects in the region, the role of architectural education in Kuwait will essentially need to allow for more understandings in ecological related principles and for interdisciplinary collaborations to forge ways for future architects to be credible for their contribution to environmental remediation and problem solving. It will enable for the cultivation of environmental awareness and empower architects with the knowledge necessary to construct spaces that provide sense of belonging for all while actively respond to environmental issues.

There is a renewed need to shift back to the smaller scale tactile urban interventions that will aid the move towards a way of sustainability that is resilient for combating the challenges we will face in the future projected changes in the climate. The “New Kuwait” needs to facilitate a return to basics through innovative design interventions, where the constructed environment is not based heavily on commercial and political needs, but respect the wellbeing of the natural landscape and ecosystems.

**References**


Fit for purpose? Sustainability and the design studio

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Abstract: The design studio is the primary means of educating architects. Since its emergence over a century ago, the pedagogy of the design studio has remained remarkably consistent despite changing demands placed upon the built environment. Preparing architects for the global challenge of sustainable design must be of primary importance to educators and requires critical and deep learning due to its holistic and interdisciplinary nature. The design studio seems the ideal environment for encouraging deep learning for sustainability through its potential to foster independent and deep learning. Despite this, sustainability is often viewed as additional, optional or even neglected entirely. The study examines a RIBA Part 2 design studio architecture course in the UK and considers whether the design studio pedagogy is fit for purpose in the context of contemporary architectural challenges. Conducted over two years, sampling two consecutive cohorts of students, the research adopts an ethnographic approach to reveal the structural and pedagogic issues that inhibit sustainable design. The findings suggest that the design studio, in its current incarnation, is not fit for the purpose of training practitioners to effectively engage with sustainability. Its introverted focus has led to a self-referential environment in which good design is defined by a "hidden agenda". A lack of effective interdisciplinary working, limited pool of teaching staff and an absence of meaningful exposure to attitudes beyond the profession are all contributing factors. As a result, sustainability is not viewed as synonymous with design quality, but additional to it.

Keywords: Sustainable architecture, design studio, sustainable pedagogy.

Introduction

In architectural education, in the UK and internationally, the design studio is the dominant pedagogic model. In a detailed study of 59 international schools of architecture conducted by Altomonte, Attia, Herde, and Kartveville (2010), the design studio, or versions of the design studio (such as design “laboratories”), is common in all countries and nearly all courses considered. It forms the central part of most courses, often carrying the majority of assessment credits.

Faced with contemporary challenges of environmental degradation, economic instability and social integration, it is imperative that architects are adequately equipped to meet these issues. Accordingly, the design studio, and its associated pedagogy, must enable meaningful learning for sustainable design. The design studio can increase critical engagement and awareness, encouraging acceptance that sustainability is a contestable and value led concept (Gürel, 2010). The design studio also has the potential to encourage transdisciplinary learning (Khan, Vandevyvere, & Allacker, 2013). However, these opportunities are rarely exploited by educators however student engagement in sustainable themes is often poor (Clune, 2014).

Current incarnations of the architectural design studio can be traced back to both the Ecole des Beaux Arts in Paris in the 19th Century as well as the Bauhaus (D. Schön, A., 1985) yet its roots reside far deeper in the mediaeval guilds and the master and apprentice model of arts and crafts education (Broadbent, 1995; Lackney, 1999). The design studio is characterised by the absence of a single body knowledge which allows individuals to develop their own work in relation to a broad and eclectic professional community (McClean, 2009).
This gives rise to a complex epistemology, in which the designer’s personal ideas allow an infinite number of possible design options (Shaffer, 2003).

This paper challenges the assumption that the design studio is fit for the purpose of educating architects to meet the demands of sustainable design. It understands sustainability as a pluralist concept (Guy & Moore, 2007) that is open to multiple simultaneous interpretations and requires deep and critical engagement. Given its historical roots, complex pedagogy, and its focus in independent learning, is the design studio still fit for purpose?

**Learning for sustainable design**

The development of independent critical thought is at the heart of both studio education (McCLean, 2009) and engagement with environmental sustainability built environment HE (EDUCATE, 2012). *Deep learning* describes a level of information processing that emphasises a holistic approach which focussing on underlying meaning (Marton & Säljö, 1976). This stands in contrast to surface learning and strategic learning which emphasise descriptions and competitiveness respectively (Warburton, 2003). Deep learning is particularly relevant to educating for sustainability due to its interdisciplinary, interconnected and holistic nature (Buckingham-Hatfield & Evans, 1996). Above all, deep learning must be internally motivated and the learner must have a desire to understand (Warburton, 2003). Accordingly, this requires student centred pedagogies to take prominence and reflective educators to enable this (Clune, 2014).

Deep learning implies a critical approach to understanding whereby assumed beliefs are challenged and reconsidered. It is a meta-reflective process, where the deliberate act of questioning action provides a deeper understanding. In the wider literature on learning, this process is variously described as *reflection-on-action* (D. A. Schön, 1984), *double loop learning* (Argyris & Schon, 1974) and *experiential learning* (Kolb & Goldman, 1973). It is an act of critical thinking which requires the processes of ‘identifying assumptions, researching them, and generating multiple perspectives’ (Brookfield, 1997, p.25).

The nature of learning that takes place in the design studio was largely undeveloped until the work of Donald Schön in the 1980s. His book *The Design Studio* (1985) built on work in *The Reflective Practitioner* (1984) and describes a number of key concepts at play in the design studio. *Reflection-in-action* describes how professionals conduct the process of design through a constant reflective dialogue during the act of creation. In contrast, *reflection-on-action* occurs after the event and allows space for the practitioner to consider their output. Through experience of the iterative process of design, students, absorb knowledge unconsciously which becomes tacit.

Schön’s reflective practice evolved from double and single loop learning (Argyris & Schon, 1974). They are distinct strategies that share commonalities with reflection in and on action. Single loop learning describes a problem solving approach whereby individuals attempting to understand internal systems in which they operate. It is concerned with improving actions to reach desired outcomes Double loop learning, by contrast, involves questioning assumptions and why action is undertaken in order to improve their inner values (Gribbin, Aftab, Young, & Park). As in deep learning, double loop learning represents a search for underlying meaning which questions both how something is done but also why it is done in that way (figure 1).
In Schön’s description of design pedagogy, Eraut (1994) suggests the designer is himself accepting the wide range of perspectives and possibilities as he tacitly explores the design process yet the transmission of this knowledge is purely didactic. The suggestion to the student is that architectural education is purely about the transmission of skills, abilities and professional competence rather than accepting it is a contested and dynamic field (Webster, 2008) undermining the potential for deep learning for sustainability. Schön also fails to note the importance of immersion in architecture, and limits his description of learning to formal encounters between master and student. Webster (2008) suggests informal learning is essential to architectural education and that high performing students engaged in ‘reading expansively, visiting cities, buildings and exhibitions, attending lectures, spending long hours in studio, and living in houses with other architectural students.’ (p. 67), characteristics consistent with a deep learning approach.

**Challenges in the design studio**

The studio appears an ideal environment for developing deep learning (Clune, 2014) for sustainability. It encourages independence, reflective analysis and critical thinking. Banerjee and Graaff (1996) assert, however, that relying on the design studio to develop a particular set of values and skills may be unreliable. Furthermore, self-directed learning may negatively impact student time and direct it away from other aspects of the curriculum (Datta, 2007). Similar observations were made by Oliveira and Marco (2016) who saw that student directed briefs often neglected sustainability. Misconceptions regarding sustainability can lead to barriers to implementation (Filho, 2000) and presenting sustainability as a vague and pluralist concept confounds this (Gürel, 2010).

Cotgrave and Alkhaddar (2006) have pointed out that there is a need for learning outcomes and module design to reflect issues in sustainability however current courses are often designed around course inputs such as resources and staff expertise. Integration must be holistic and coherent as fragmentation, ad-hoc additions and non-uniformity may prevent meaningful integration (Cotgrave & Alkhaddar, 2006).

The development of the design studio leaves one questioning the alignment between its pedagogy and intended outcomes. The master-apprentice model, on which the studio was founded, poses particular problems for developing deep sustainability. The challenges of sustainability require innovative approaches, picking apart widely held assumptions, and considering alternative ways of acting. Dutton (1987) points towards a powerful hidden
agenda of the studio that both intentionally and subconsciously the it acts to legitimise certain types of knowledge and practice. Underpinned by hierarchical social structures and unchallenged assumptions, each design studio or school of architecture delivers a particular form of architectural and professional agenda (Dutton, 1991). This professional validation, generated by institutionalised power asymmetries, necessarily excludes alternative forms of practice and in turn, validates the profession and promotes ‘a series of self-referential and autonomous values’ (Till, 2003). In the search for innovative processes, underlying meaning and challenging assumptions, ‘thinking like an architect’ (Weaver, 1997) may prove problematic. Stevens (1995) notes the tendency of architectural education to ‘favour the favoured’ that is to preserve the status quo of the profession limiting its social diversity. Placed in the context deep learning, this limits the exposure of students to multiple points of view, reinforcing professional assumptions and behaviours undermining critical understanding (Brookfield, 1997).

Perhaps the biggest barrier to learning for sustainable design in the education of architects comes from the professional and institutional culture it operates within. Murray and Cotgrave (2007) suggests that despite the minimal requirements of sustainability in the curriculum laid down by professional bodies, the major hurdle to overcome is a professional one. Alabaster and Blair (1996) note that academics in HE are often resistant to values imposed from outside their subject areas. This poses a particular problem to the interdisciplinary nature of environmental sustainability.

Context of the case study

Learning in the studio at the case study university is focussed around design projects, developed both for and by students. The design project is the vehicle for learning; the design studio provides its context. While deep and experiential learning may underpin the epistemological motivations of the studio these cognitive processes are framed through the process of design itself which has its own codes and conventions. At the case study university, the critical method (CM) is explicitly advocated as a model of design. CM is passed on the critical rationalism of Popper (1963) and was applied to design initially by Darke (1979) and developed by Brawne (2003). It describes a process of conjecture followed by analysis or, in the terminology of Brawne (2003), tentative theory followed by error elimination. CM is an iterative process of informed guess work (Bamford, 2002) tested through the application of professional tools (drawing, modelling etc.). Darke (1979) proposed a further aspect to the cycle: the primary generator. A primary generator, also termed the design concept, describes the initial starting point of the process based on the designer’s preconceptions, experiences and personal motivations. It is most often an article of faith, a collection of conceptual ideas, rather than a rational list of constraints (Darke, 1979).

In the context of deep learning for sustainability, the reflective cycle runs parallel to CM: initial assumptions constitute primary generators; action generates conjectures; and design solutions provide experiences. Accordingly, in order for effective deep learning for sustainability to take place, it is not enough for the design cycle to consist of only conjecture and analysis generating new conjecture, as suggested by (Brawne, 2003). Instead, the designer must constantly return to their primary generators, questioning their initial underlying assumptions in light of newly created design knowledge.

The field of study was a final year MArch design studio at the case study university. This allowed participants to have a reflective view on their architectural education and were most likely to go into architectural practice, maximising potential impact of the research. The
MArch course is organised through a single studio in which all students undertake a self-defined project in a European city of their choice. The first half of the year is organised into groups, each of which undertake a master-planning project. The second half is an individual project in the chosen city with a brief defined by the student. Studio tutors support the students and in the second half of the year each student is assigned a tutor to guide them through the project. The participants had a sophisticated level of design ability and could articulate values and understand issues.

Method

The research was conducted in situ and results are contextual, value-bound and consist of various overlapping realities which generated working hypotheses, rather than concrete theory. It is purposive, and sampled an individual context and responded to the particular characteristics of the population (Lincoln & Guba, 1985). The research utilised a qualitative approach using direct (rather than remote and inferential) methods to capture individual points of view and the messiness of everyday life. The findings are embedded within this context. The paper uses a “rich” description to provide detailed accounts of the study (Denzin & Lincoln, 2011).

The research took place over a two-year period. An ethnographic study was undertaken to identify issues and possible domains for change. The participants in the study were final year MArch (RIBA 2) students at the study university. The participants were typically in their sixth year of formal architectural education. The researcher was a member of staff at the case study department but not directly involved in teaching on the MArch course in order to avoid possible bias. The role of the researcher was predominantly one of observer-as-participant (Gold, 1958). In this role most data were gathered through relatively formal settings, (scheduled interviews and planned observations) in which the researcher was considered ‘acceptable incompetent’ (Lofland, 1971). In all cases the participants were aware of the presence and role of the observer. The researcher’s role allowed a passive approach that limited impact on the students. The openness of the study and knowledge of participants negated the potential ethical implications of a more immersive researcher role. It allowed a broader data set to be gathered, maintained a suitable distance from the subjects and avoided possible ethical issues. Consideration was also given to discretion in interviews, responsibilities to student welfare, preferential treatment and respecting the attitudes of student to remain anonymous.

Data collection involved a cyclical process of collection, analysis and validation which informed further cycles (Cohen, Manion, & Morrison, 2000). A voluntary sample of 20 participants within the population (n=70) were interviewed using semi-structured interviews (Patton, 1980). This provided a baseline understanding and informed further data collection and analysis. 4 educators on the course provided supplementary interviews. Observations of crits and tutorials were undertaken by the researcher in a naturalistic manner (Lincoln & Guba, 1985). These provided a formal educational encounter which gave data on the students and educators. Observations were noted and categorised in-situ paying particular attention to the theming of discussions taking place as well as the nature of this dialogue.

Analysis of the data occurred in tandem with collection allowing a continuous process of verification and theory generation (Cohen et al., 2000). On a practical level, the researcher could deal with a large quantity of data and sufficiently narrow the field of inquiry in later study. The data were analysed in a seven step process in which data were unitised (coded), clustered into domains, relationships established, inferences made, summarised, negative
cases sought and theory generated (Cohen et al., 2000). NVivo, software which supports qualitative research, was used to analyse and code the data. Writing the report is an important aspect of the naturalistic research process, and accurate representation of the research situation is essential to achieving trustworthiness (Lincoln & Guba, 1985). It is essential that the report catch and portray to the reader what it is like to be embedded in the specific case study (Cohen et al., 2000). In line with the guidelines set out by Lincoln and Guba (1985) the report writing focussed on the presentation of facts linked to the collected data, anonymised participants and began by over-including data which was then edited (p.365-6). The report writing process occurred in a cycle with the data analysis, allowing categorisation of data, and informed recoding and restructuring of the data.

Results

Curriculum and structure

The curriculum set for the design studio at the case study university consists of a series of assignments, assessed against set criteria known as Independent Learning Outcomes (ILOs). The ILOs were drawn directly from the graduate requirements of the ARB and RIBA (Architects’ Registration Board, 2010; Royal Institute of British Architects, 2010) of which four deal with environment and sustainability. At the case study university these ILOs are removed from the design studio and covered in a separate unit taught in the first year of study in order to allow relative “freedom” in the design studio. The unit convenor for the design studio described the ILOs as the “point of failure” for the unit.

Sustainability was covered in the general briefing document for the studio assignment, in which, as one staff member put it:

“...there is an explicit paragraph about sustainability issues and they should be explicitly addressed, but the response to that given the nature of the buildings and the locations is by definition broadly trying to make a catchall statement.” (Michael, Director of Studies)

One student described the impact of this explicit description in the brief:

“...it becomes our design agenda ... we are creating a sustainable city. It’s in the name so you’re almost forced to do it.” (Georgina)

While raising consciousness, this explicit framing also placed sustainable design as an isolated topic, separate from more conventional architectural approaches.

A number of additional lectures and satellite modules that ran parallel to the studio. In the case study MAarch studio, the participants had undertaken a 10 week lecture course on sustainability and environmental design in the first year of study. Despite being unrelated to the design studio, the lectures were considered valuable by students as providing “core” knowledge. The course administrator also spoke of the need for sequential learning to adequately integrate sustainable design holistically into design projects. Despite the perceived necessity for lectures to supplement studio work, there was little evidence of the taught content from lectures manifesting itself in design projects. Sustainable strategies were specific to projects and individually researched. One student highlighted the abstraction of lectures and its seeming irrelevance to design studio work while another described the “disconnect” between learning in lectures and the studio:

“There is a disconnect between what you learn in lectures and what you actually do in the studio. I don’t think I used anything that I learnt in lectures to what I do in my design studios.” (Simon).

Studio pedagogy
The design studio at the case study university underpins the curriculum at the case study university. Assessment of the design studio through completed project work forms 70% of the final degree classification. Accordingly, this is based on the assumption that the design process itself is an educational one. Students were able to integrate sustainable concerns throughout their projects, from initial ideas to detailed designs.

“for example on the site, where we put the building on that site and that is one of the first considerations of the environmental strategy...then later on you can consider the environmental strategy again as to what sort of technology you can put in your building to make it more sustainable.” (Simon)

The application of sustainable principles through to design projects was a clear concern among students however it was typically seen as a series of additive measure that could be overlaid onto completed designs. Learning was often restricted to technical knowledge about particular systems and lacked “meta-knowledge” and holistic thinking. Students spoke of it being “put on at the end [of a project]” (Laura), “applied” to the project (Chris) or in some cases in viewed as optional or impossible:

“I’m not sure whether it’s realistic that you do consider the environmental aspect of ever project.” (Simon)

There was an explicit attempt by educators to get students at MAarch level to adopt holistic and “whole-system” approaches. They spoke of student’s varying levels of engagement with sustainability in their design projects however noted a lack of a fundamental integration.

“I’ve never been led by a student into discussing their design thinking, in what I would describe in the broadest definition of sustainable ideas.” (Michael, Director of studies)

Adopting design as an educational process placed emphasised a practical, problem solving approach to sustainability as well as generalised, non-specific strategies. This tended to manifest itself in technical solutions to issues which demonstrated integration but undermined more holistic approaches. According to one educator, this was exacerbated by the experience of tutors, who mostly consisting of practitioners. The nature of the design project as a medium for learning tended to undermine rigorous and in-depth analysis. A number of students expressed a desire for quantitative processes:

“In the design studio it’s hard. For me sustainability comes out in the excel spreadsheet really. You can sort of convince in the design studio but really it’s hard to quantify.” (Phil)

Others felt the lack of genuine analysis could mask basic or ill-conceived approaches:

“if you want to avoid it you can avoid it easily” (Anne)

The design studio was characterised by individual freedom and independent learning. Students were able to choose their own design projects and explore themes important to them. This enabled some students to explore overtly environmental agendas (such as a research centre for climate adaption) and develop knowledge beyond that of their tutors. For others, this freedom allowed them to all but avoid environmental concerns:

“This is seen as your opportunity to be free in design and be as creative as you can and if you perceive that as something that hinders creativity or is it another thing that gives you constraints that may help you design something better.” (Jane)

The lack of sustainability focus was in part due to the complexity of a design project. One tutor described it a “complex Venn diagram” with sustainability occupying on one small section. This open-ended complexity requires students to construct their approach based on prior interests, values and assumptions.

Agenda and values
The design studio was observed to embody implicit values which had considerable impact on design for sustainability. There was clear value placed on the design process as iterative, involving trial and error and the disposal of physical artefacts, rarely recycled. One tutor described the environment of the design studio to “tend not to look like the sort of places where people are concerned with materials. The material is visibly wasted and treated quite badly and not valued.” (Michael, Director of studies)

Students and tutors both described a set of underlying “agendas” for design which were perceived as conflicting with, or undermining, sustainability. One student expressed this tension as the difference between something being “design led” and sustainable (Martha) while another described it as the balance between aesthetics and sustainability (Jane). This dichotomy was echoed by tutors; one spoke of the students who designed with an “architectural aesthetic and visual approach” in which sustainable concerns were secondary (Alan, sustainability tutor) while another described other more practical design concerns (such as the location of the front door or the sizes of the rooms) taking precedence (Michael, Director of Studies).

Sustainable design was often seen as uninteresting to students and not appreciated by critics or tutors. In most cases it was seen as additional to the primary agenda to the project, something that might be added on at the end:

“I find students who really have impressive environmental strategies do that in a modest way that isn’t necessarily celebrated through the projects and it’s students who do crazy processes of their building type which is far more interesting.” (Martha).

The overarching explicit agenda of the department had a mixed impact on students. While tutors suggested that the department focussed on sustainability more than at other schools of architecture, student perception varied, based on comparisons with prior educational experience. Despite a strong sustainable research agenda in the department, little of this filtered into the design with most researchers having no connection to the course. Tutors were either full time teaching staff (non-research) or external practitioners who taught part-time.

Students’ own experiences had a strong impact on their approach to sustainable design. Study visits such as trips to buildings and cities were key for raising awareness of sustainable issues. Despite all students having between 1 and 3 years of professional practice experience, few spoke of this time as being particularly influential on their outlook. A number of students demonstrated strong personal motivation. For example, three of the students had undertaken Passivhaus courses in their own time while another had been to a sustainability conference. Many demonstrated personal motivation and aspired to sustainable lifestyles however did not translate these values into the design studio, a view echoed by staff.

“…[I am sustainable] more outside of architecture…so things like in my household we’re quite keen on measuring energy usage and involved in community projects, that kind of stuff.” (Martha)

“…they [students] talk a good game but in reality they don’t act a good game.” (Michael, Director of Studies)

Teaching interactions

Formal student and tutor interactions in the design studio primarily took place in two different teaching events; tutorials and crits. Tutorials describe an in studio session normally involving a single student and tutor (on group projects this was a group and one or two tutors. Crits were formal presentations in which students pinned their work on the walls and
presented them in front of a panel of “critics” (normally comprising of tutors and invited external experts).

Tutors saw their roles in different ways. The sustainability tutor (Alan) saw himself as “a facilitator and someone who gives strategies and techniques to employ” operating as an expert consultant. Conversely, Michael (tutor and director of studies) viewed tutoring as “purposefully avoiding closing things down and avoiding solving problems for them and proactively try to listen a lot and talk less and try and get them to say what they were thinking more”. From observed tutorials, while these different styles were apparent, the tendency to proffer design ideas was prevalent. Of the six tutors observed or interviewed, those who were thought of in a technical capacity (such as Alan) identified problems and offered “solutions”, continuously drawing and working through the design. By contrast, other tutors relied almost entirely on verbal communication however were still observed to raise issues and describe potential solutions.

In all cases, tutors were influential on the work of the students. Students described how specific design ideas had originated from their tutor, or how a particular tutor had directed them to explore a particular theme. This influence could encourage a student to place sustainable design at the heart of their work. In other cases, students felt their tutor was not interested in sustainable design or “didn’t real necessarily talk about it” (Yvonne).

Crits were predominantly student led; students chose what work to present which in turn directed the nature of the conversation. For example, in an observed crit, one of fifteen discussion topics were focussed on sustainability, and in another, only three of twenty. By contrast, in one scheme where the students had developed a particular strong sustainable agenda, eight of the twelve discussion points centred around sustainability concerns. As well as the content of the crit, its format (45 minutes long analysing work pinned up on a wall) led to graphical and verbal presentations which favoured clarity and brevity at the expense of rigour and ambiguity. Students felt the need to produce “flashy” images, while others noted the inadequacy of the crit to showcase technical design.

Discussion

The design studio represents a complex and multi-faceted learning environment in which the simple addition of sustainable design content has limited effect, supporting the assertions of Warburton (2003). While the need for RIBA and ARB compliance ensures curricula address sustainability concerns, the possibility to extricate these ILOs into satellite units, unrelated to the design studio avoids the need for integration. Moreover, the consideration of learning outcomes as the “point of failure” of a unit relegates them to the level of compliance. Integration is far more successful when it is made the “theme” of the design studio and is overtly described in assignment briefs. This points to a fundamental misalignment between learning outcomes and design expectations.

The foci of the design studio are governed by underlying values that determine good design. This “hidden agenda” (Dutton, 1987) describes a self-validating approach to architectural design in which students, staff and practitioners define primary architectural concerns through the development of a tacit, internalised language. Sustainable design is often seen to be at odds with design; students spoke of the need to balance these two competing concerns. While the literature on sustainable design advocates interdisciplinary working that draws from a range of different backgrounds (Jones, Selby, & Sterling, 2010) the design studio is taught by practitioners of architecture who themselves were educated in the same system. This generates an echo-chamber in which external influences are limited and
alternative perspectives denied. This has led to an internalised validation system that fails to address challenges beyond the assumed scope of architecture.

Educator and student interactions limited the possibility for sustainable design. With the exception of one tutor who adopted a highly theorised, psychoanalytical approach, tutors rarely critically questioned assumptions, but rather engaged in mimetic processes such as drawing ideas or verbally describing possibilities. Questioning students was normally to clarify points. This reflects Schön’s (1985) description of architectural teaching in which the tutor demonstrates reflection-in-action. In the context of education for sustainable design however, this was seen to limit deep learning. Not only was the learning restricted to the absolute knowledge of the tutor, but the teaching failed to address the holistic, interdisciplinary and critical approach required for deep learning (Buckingham-Hatfield & Evans, 1996). In crits there was an emphasis on presentation and product to aid communicative clarity. For some students, this either undermined or removed the need for procedural rigour. Crits were student-led and discussions surrounding sustainability relied on the nature of the work presented. This corroborates the work of Datta (2007) and Oliveira and Marco (2016) who suggest self-directed learning can exclude sustainability concerns. A lack of engagement in sustainability was partly blamed on the perceived attitudes of critics and tutors, whom many students considered not to value it, reinforcing accepted institutional and professional practices.

The pedagogy of the MArch studio served to develop reflection-in-action (D. Schön, A., 1985), the ability to think like an architect, yet this was confined by a narrow frame of reference. This limited the ability to address sustainable issues, challenge assumptions and create a wide variety of innovative proposals, and prevented genuine deep learning for sustainability. Nevertheless, the studio provided space for individual engagement with the four stages of Kolb’s learning cycle through individual project led learning (Kolb, 1984), however concrete experiences and abstract conceptualisation was restricted to a narrow sphere of knowledge. The MArch studio provided the illusion of independence but student process and learning were both consciously bound (through the requirements of assignments) and subliminally influenced (through exposure to a limited range of experiences and perspectives) by the context of study (Ward, 1990). Ultimately the design studio was seen to be a single loop learning environment (Argyris & Schon, 1974) in which basic assumptions were rarely challenged.

The challenges of the design studio to adequately adapt a sustainable future may be attributed to the nature of the design-problems that the studio has evolved to deal with. The focus of the design studio on generating well-formed “solutions” emphasises production over process and learning. Not only is sustainability “wicked” in nature (Rittel & Webber, 1973), but it also relies on holistic, collaborative, interdisciplinary and critical learning (Howlett, Ferreira, & Blomfield, 2016). The autonomous problem-solving approach of the design studio, disciplinary focus and dependence on professional competence is inadequate for educating to meet the challenges of sustainability.

Conclusion

In order to successfully transform the design studio to engage with the challenges of sustainable design, it is not enough to merely add content or demand compliance. In the case-study, the structure, agenda and pedagogy acted as the primary barriers to successful integration. To educate for sustainable design, the findings suggest the design studio must embrace alternative perspectives and interdisciplinary working. Educators must be drawn
from a variety of fields with a diverse range of backgrounds in order to break the introverted cycle of design validation. Theming design studios around sustainable design which can encourage early integration and the creation of sustainable narratives. The emphasis on design product, prevalent in the case-study, should be shifted to process which embraces holistic design approaches that challenge conventional understanding of sustainable design. Deep learning must be facilitated through the creation of an environment which constantly questions underlying assumptions and values a plurality of design approaches. Exposing students to a variety of external experiences may also raise critical awareness and engender intrinsic motivation for sustainable design. Ultimately, the specific pedagogy of the studio is drawn into question. Developing independent learners in an apprentice-style environment limits the holistic and critical thinking required for sustainable design. This study has implications for both educators and professional bodies. Educators must rethink how the pedagogy of the design studio may be evolved to address sustainable design. The ARB and the RIBA must reconsider the role of required graduate attributes and how these impact design teaching. Further work might expand this study to other schools of architecture to validate these findings and assess its transferability to other contexts.

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Sustainable Information and Communication Technology (ICT) Initiatives in UK and Irish Universities and Colleges: Identifying and Overcoming the Barriers to Implementation.

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Abstract: Energy is one of Ireland’s and the UK’s biggest commercial and environmental concerns. Despite government campaigns for everyone to play their part in minimising its consumption, reports suggest an estimated 20–30% of energy generated is wasted. Further and higher education institutions (FHEs) are no exception to this wastage using an extensive collection of ICT equipment and technology for teaching and research. Such technology is often left running when not in use creating energy waste, increasing running costs and carbon emissions. Conducted over the course of three consecutive stages, this research employed positivistic and anti-positivistic paradigms, utilised inductive, abductive and deductive methodologies and employed comparative, correlative and evaluative research methods that answer the research question and sub-questions. This research showed that a gap in knowledge within the sector existed. That gap in knowledge – the identification of barriers to FHEs implementing sustainable ICT initiatives – is central to this research, as is how the gap was eventually bridged. Data were gathered throughout this research using surveys and questionnaires. Seven barriers to implementing ‘greener’ ICT initiatives were eventually identified with three of them (stakeholder engagement, lacking managers and cuts in funding) found to be widespread. Each of the barriers existed to various extents, in both countries and were experienced by a range of FHE managers with most underpinning one another. Finally, this research demonstrated that overcoming the barriers proved possible via the use of a smartphone web app named the ED web app. This simple to use and inexpensive ICT solution is easily replicated and engages with stakeholders in tackling energy waste in any organisation. These findings validated this research’s theory and ultimately answered the research question and its sub-questions.

Keywords: Sustainable, Information Communication Technology (ICT), Universities and Colleges, Stakeholders, Barriers.

Introduction

From 2010 to 2014 there existed a series of problems relating to environmentally unsustainable practices within the Scottish, UK and Irish further and higher education sector. One of the most pressing environmental problems pertained to energy use and even worse, energy waste. Such poor unsustainable performance typically results in wasted resources, disgruntled managers and dissatisfied students (Enochs, 2012; People and Planet, 2012; EAUC, 2016b). Universities and colleges are typically long–lived institutions that operate like small villages where the investment of time and money into robust environmental frameworks will prove frugal and socially responsible (Hammond-Creighton, 2006; Reza, 2016; Zou et al., 2015). However, implementing sustainable initiatives is rarely a simple, quick or even straightforward process (Hogan, 2009; James and Hopkinson, 2009; Velazquez et al., 2006; Sharpe, 2002). In reality such initiatives are complicated and fraught red tape. Fortunately, for each obstacle and barrier to implementing an energy saving initiative, there exists a solution, underpinned by sufficient funding, adequately resourced managers and
Sustainable ICT

The institutional benefits of using sustainable ICT equipment are numerous (Worthington, 2010). The most obvious one is the financial savings that can be gained by utilising more energy efficient equipment (James and Hopkinson, 2009; Baroudi et al., 2009). Consuming less electricity also means releasing fewer CO$_2$ emissions so carbon targets are achieved (Carbon Trust, 2016a; GOV.UK, 2014a) and savings made year on year in energy costs, through the use of more sustainable ICT equipment, can far exceed initial purchase costs. In fact, such cost can be recouped in as little as two years (Jeffrey, 2011; James and Hopkinson, 2009). ICT is even being used as an enabler for improved sustainable performance as smart meters facilitate the reporting of real-time energy consumption and mobile devices allow for social activism of stakeholders (Bull et al, 2014; LoveCleanStreets, 2016; Suliman, 2018.). The SMART 2020 report revealed that ICT’s unique ability to monitor and maximise energy efficiency, both within and outside of its own sector can lead to emission reductions five times the size of the sector’s own footprint (GeSI, 2016). However, improving an institution’s environmental performance firstly involves identifying any barriers that may be causing poor environmental performance to begin with. This research does exactly that, specifically focusing on barriers to implementing sustainable ICT initiatives. It also offers a solution to overcoming these barriers in the form of a webapp, called the ED web app.

The Three Stages of this Research

This research ran from 2010 to 2016 and evolved over the course of three different stages. Stage 1 of this research pertains to the outcomes of the Scottish and UK ICT Carbon and Energy Management Project. Both projects examined the energy use of ICT equipment in 16 FHEs and offered free consultancy support for participants willing to gather data pertaining to their ICT energy use. Participants were also asked to replace their old energy inefficient equipment with ‘greener’ technologies (at their institutions expense) and then share their findings relating to energy savings with the sector. Participation by FHEs in both projects proved much slower and intermittent than anticipated and after some investigation, it was discovered that a combination of a lack of time and of resources to devote to either of the projects were the predominant reasons given for such poor participation. In short, it was realised that barriers to more sustainable management of their ICT equipment existed but required more investigation.

It was also during Stage 1 of this research that the research question – Identification of principal barriers to optimal sustainable performance in universities and colleges and how a series of ICT-related solutions can overcome those barriers – was conceived along with the conceptualisation of what other possible barriers might exist. Those possible barriers are explained below:

1. **Lacking Managers.** This principally refers to, but is not exclusive to, ICT managers. It includes sustainable and environmental managers, estates managers, energy managers etc. The term “lacking” refers to managers who are struggling to perform optimally in their roles for various reasons.

2. **Poor Stakeholder Engagement.** In the context of this research, this refers to poor inter-departmental engagement on green ICT issues. It refers to a department requesting information from another but not receiving it, receiving it only in parts or in an untimely fashion. It also refers to departments that consider sustainable ICT issues as being...
unimportant and not “core business” to their institution, outside of their remit or the responsibility of someone else.

3. **Institutional Culture.** This refers to institutions that have no history of engagement with sustainability via either their operations, curriculum or research and may consider them unimportant.

4. **Government Organisations as Weak Drivers.** This refers to government organisations that penalise institutions that do not reach their carbon targets.

5. **Budget-holders and Decision-makers’ Collective Action/ Buying of ICT/IT equipment.** This pertains to procurement departments and senior managers who inhibit the purchase of sustainable ICT equipment for various reasons including not being part of a purchasing framework and/or not supporting staff in their need to purchase greener ICT.

6. **Sustainable Technology.** This occurs when sustainable technology does not produce the cost and carbon saving results it promised and institutions deciding to no longer continue participation in green ICT projects.

7. **Cuts in Funding/Revenue Streams.** This is when institutions can no longer participate as a result of cuts in funding to their institution and/or their department. This includes cuts affecting staff workload, allocated number of hours and salary.

**Stage 2** of this research involved the circulation of a large and detailed survey whose questions were based on the possible barriers listed above. Circulated to over 200 FHE managers in the UK and Ireland, the results of this ‘main research survey’ indicated that all seven barriers had been experienced by a variety of FHE managers, to varying degrees with the existence of those barriers varying between institutions in both countries.

After establishing that all seven barriers existed, the next stage of the research, **Stage 3,** was to find an ICT based solution that would overcome those barriers. Named the ED webapp, it demonstrated how when used in conjunction with a smartphone allowed for at least three of the barriers to be overcome. The webapp administered data in relation to energy wastage while at the same time allowed staff and students to engage with the concept of participating in the sustainable operations of their campus.

**Research Paradigms, Methodologies and Methods**

This research employed different research paradigms, methodologies and methods in each of the 3 stages of this research. **Stage 1** involved case study research with the case studies being a Scottish and UK based Energy and Carbon Management Plan. As the research progressed, a series of seven barriers were identified. Research into the barriers was therefore considered inductive and the methodological approach was anti-positivistic, employing qualitative methods of research. As the research evolved further in the form of examination of the results of the main survey and examination of the outcomes of case studies, it became positivistic and abductive, employing mixed methods of research as data were being tested against a set of parameters. Finally, armed with new knowledge on barriers to implementation of ICT initiatives, ‘barrier-free’ action research took place, in partnership with engaged and coordinated stakeholders (Costello, 2003) that was positivistic and deductive, employing quantitative data. This final stage of the research is known as Stage 3.

**The Research Question Surveys**

The research question which evolved out of Stage 1 of the research asked: what are the barriers and limiting factors that inhibit the realisation of the potential benefits to UK and Irish universities and colleges of implementing sustainable ICT initiatives?
Its follow on sub-questions asked; what are the key implications of those barriers? and How can a sustainable ICT solution alleviate those barriers?

The UK and Irish main research surveys were circulated via e-mail to over 215 UK and Irish FHE sector managers in November of 2014. Six of the seven questions offered a “Yes, No or Somewhat” response option with follow-up answer options asking why respondents may have chosen that answer. The UK survey was circulated to the EAUC-London JISCMail mailing list and to members of Ireland’s An Taisce’s ICT mailing list. The UK survey achieved a 41% (60/146) response rate and the Irish survey a 23% (16/69) response rate, averaging out at a 35% (76/215) response rate. The surveys were conducted online using SurveyMonkey and included a total of nineteen questions.

The questions asked included:

(i). When implementing "greener ICT" in your institution, were stakeholders (staff and students, other organisations etc.) engaged? I.e. were they willing to adjust to changes in job roles, train in the use of greener technologies etc.?

(ii). Is participating in green ICT projects typical of your institution's culture?

(iii). Of the government organisations listed (HEFCE, DEFRA, DECC, Salix, Local Authorities, Other Government Funded Organisation) please state how they have affected your institution’s participation in green ICT projects (Excellent Driver to Very Poor Driver).

(iv). Do you feel that green technology delivers on the financial and carbon savings promised by IT companies?

(v). Have recent cuts in funding to the educational sector affected your institution’s ability to participate in sustainable ICT projects?

(vi). Assuming your institution is part of a framework (e.g. LUPC) that includes criteria for the purchase of sustainable technology, do you feel you are supported in your choices to purchase more sustainable technology?

(vii). Do you feel your institution’s ICT manager(s) are "lacking" by exhibiting any of the characteristics below?

The individual results of both survey coupled with a three-way cross-comparison of their results are too numerous and detailed to be included in this conference paper so the researcher has chosen to summarise them in a single table, Table 1.

Table 1. Summary of Presence or Absence of Barriers by Geographical Location and Category of FHE Manager.

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<td>Poor Stakeholder Engagement.</td>
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Results of the surveys validated the theory that each of the seven barriers existed and ultimately answered the research question. A cross comparison of three different data sets of results from both surveys were then examined to establish any patterns regarding each of the barriers.

Summary of Results of Comparison of Responses between UK and Irish Surveys

Results of the UK and Irish surveys included a mixture of both similar and differing opinions regarding each of the seven barriers. Some answers indicated a strong similarity between the two countries yet in other instances, they had opposite views on whether a barrier existed or not and to what extent. Results of the UK and Irish surveys were then cross-compared from three different aspects and showed that London institutions appeared to be more sustainably minded and appear to take action where practicable. There also appears to be a strong sense of community within the London universities as evidenced in the large number of responses to the survey. The largest lacking characteristic recognised was being negatively influenced by institutional politics, with the majority of other managers indicating this as a barrier also. In contrast, this was also the least commonly occurring lacking characteristic where ICT/IT managers were concerned. However, when each of the lacking characteristics are totalled, being under-resourced in terms of funding for new technology is the most common barrier to participation in sustainable ICT projects. Other commonly-found barriers include being under-resourced in terms of allocation of support staff, allowances for staff training and having a disinterest in outside green ICT, amongst others. While some respondents indicated that their ICT managers were not lacking in any of the characteristics listed, overall, responses from each category of manager indicated that each of the barriers exists to varying degrees. In short, results of both surveys confirm the presence and absence of each of the seven barriers and highlighted considerable overlap in many of the responses. They also highlighted the disparity in many of the results, where, not only did barriers not exist in institutions, they were offered significant support in implementing the use of more...
sustainable technology and in engaging staff and students with sustainable behavioural change.

**Overcoming the barriers**

Having identified the barriers in stage 1 and 2, the researcher focused on finding a sustainable ICT solution that would alleviate those barriers. That ICT solution needed to engage with stakeholders, be a useful resource to lacking managers and help institutions overcome cuts in funding, while at the same time being convenient and easy to use and cost free to the user. From these criteria, the ED mobile web app was created and implemented over four cycles of action research conducted at a London university. These cycles of action research (not included in this conference paper due to limitations of space) was the third and final stage of this research.

**The ED webapp and how it works.**

The webapp is essentially a webpage accessed via a smartphone or PC, which allowed staff and students to report where and when they saw energy being wasted across campus. The ED webpage consisted of a drop-down menu of the list of buildings on campus along with the type of wastage occurring so users could make their choices accordingly. Users could also take a picture of the classrooms or spaces where energy was being wasted as further evidence. They were also asked to prevent further wastage by switching off whichever category of energy waste they saw occurring (lights or ICT equipment left on). All energy wastage reported was stored on a central server that could be accessed by the researcher who monitored the data and frequency of reports. Upon examining the ED reports and comparing them against real-time reduction in energy waste, it was determined that the ICT solution, the ED webapp, worked.

**Cost and Carbon Savings via the ED Web App.**

In order to gather quantitative and qualitative data the researcher examined reports of energy being wasted over a four-month period, from January to May 2016. In total 305 incidents of energy being wasted were reported and ‘actioned’ (lights and ICT equipment switched off at the time of reporting), preventing a further 3,522 hours of ICT and lighting energy being wasted. This number equated to savings of approximately £370 and a reduction of 1.02 tonnes of CO₂. These savings were calculated by multiplying the time the switch-off was recorded via the ED web app until 8am the following day. Those numbers of hours, typically between thirteen and fifteen hours per classroom, were then multiplied by the average energy requirement of each piece of ICT equipment and light (varied from room to room and between pieces of ICT equipment) and multiplied by the cost per kWh of energy (0.104p per kWh hour). Calculations estimated that from January 2016 to April 2016 approximately £162.00 was saved by ED webapp users switching lights off. In addition, a total 622.kgs of CO₂ was saved from lights not being left on and 135 kgs of CO₂ from PCs/Macs not left running. Total savings amounted to approximately £190. Carbon emissions were calculated using the Carbon Conversion Factor of 0.40957 as given by the DECC (DECC, 2016).

**Overall Discussion and Conclusion of the Research Findings**

Results of the surveys have validated, that each of the seven barriers existed. By virtue of their existence, they answered the research question: what are the barriers and limiting factors that inhibit the realisation of the potential benefits to UK and Irish universities and colleges of implementing sustainable ICT initiatives? Results of the surveys and the action research carried out at a London university involving the creation of the ED webapp, also answered the research sub-questions; what are the key
implications of those barriers? and how can a sustainable ICT solution alleviate those barriers?

It can also be concluded that while some barriers are clearly connected, others appear to be separate. It can also be concluded that one barrier underpins the others (Hogan, 2012). For example, when sufficient funding is in place, institutions are afforded the time and resources to complete projects. This includes the provision of staff training and assistance, the purchase of necessary equipment and the engagement with organisations that charge for the service of their advices. Sufficient and continuous funding to the FHE sector is essential to its development and expansion. Without it, institutions cannot remain competitive, the quality of teaching and research suffers and sustainable projects are scrapped or pressured to finish earlier (UUK, 2016a; HEFCE, 2016; THE 2012, Hogan, 2009). As stakeholder engagement in FHEs now includes students and staff, local councils, SMEs and local residents, each contributing to an institution’s survival (O’Boyle, 2012), their poor level of engagement resulting in sustainable under-performance, may also be considered a barrier (Allman, Fleming, Wallace, 2004).

Another example is disjointed stakeholder engagement and how it occurred as a result of a breakdown in communication between managers in the same institution or between local councils. This may have been for a number of reasons such as a change in management, job remits expanding and departments downsizing or consolidating. Either way it is a barrier that is often interconnected with other barriers and is rarely found in isolation (Schawbel, 2013; Egeland, 2009; Suryawanshi and Narkhede, 2015). This research has demonstrated the importance of continued stakeholder engagement and to ensure managers are adequately resourced for the full duration of a project which should be considered an essential prerequisite for university initiatives, sustainable or otherwise.

Any engagement with greener ICT initiatives, that did occur was likely to be as a result of being informed of any changes being made and those changes being implemented gradually. Any disengagement from either region was as a result of a resistance to behavioural change and a lack of confidence in those green ICT initiatives (d’Arjuzon, 2012). It can be concluded that green ICT is more part of the culture of institutions from both parts of the UK, than not. This is because of the younger workforce who completed the survey and who are more knowledgeable about technology and its impact on the environment. This younger workforce made a unique contribution to this research (Coughlan, 2017; Garthwaite, 2017; Folkman, 2015).

Overall government organisations were not considered to be very strong drivers by institutions in either London or the Rest of the UK (Randerson, 2010; Plumer, 2013). This will have contributed to such poor levels of participation in green ICT projects. Institutions in the Rest of the UK indicated that green technology delivered on the financial and carbon savings promised by IT companies, more so than London institutions. London institutions’ sole reason for not believing in the benefits of green ICT was that purchase costs exceeded any saving recouped in reduced energy costs. The disparity between London and the Rest of the UK responses is therefore due to the overall higher cost of living London (Numbeo, 2017; Rej, 2016).

Results of the survey also indicated a lack of education and training in institutions in both London and the Rest of the UK regarding membership of purchasing frameworks and any support such frameworks offer. Barriers that affect London institutions in participating in sustainable ICT projects, also affect institutions across the Rest of the UK and in similar
amounts too. This further demonstrates the similarity in management set-up and operations of all FHEs and that barriers exist in every organisation (Barry, 2007: 2013).

There was a mixture of opinions regarding green technology delivering on the financial and carbon savings promised by ICT/IT companies from each of the three categories of managers. Similarly, this is because each category of managers has a difference experience in the use of green ICT and in its delivery of cost and carbon savings (Hogan, 2011a). Cuts in funding affected each of the managers differently with Environmental/Sustainability managers indicating not being affected at all. Similar responses were given the in 2012 Cuts in Funding survey (Hogan, 2012), where FHE managers indicated having less funding as an opportunity for reducing consumerism and thereby reducing their overall environmental footprint. It can also be concluded that there is cross-departmental awareness of purchasing frameworks in UK institutions, but levels of awareness amongst managers is mixed and this sometimes leads to less sustainable decisions being made (Hogan, 2011a; CIPS, 2009 pp3–4).

A key implication of being under-resourced as regards support staff, allowances for staff training and having a disinterest in outside green ICT projects is that, combined, are the most undermining and debilitating characteristics of a lacking manager (Enochs, 2012; Guardian Work Blog, 2013). However, in contrast some institutions have ICT/IT managers who claimed to not be lacking in any way. This is due to their working in silo and having minimal engagement or interaction with stakeholders and therefore were unaware of any issues, environmental or otherwise, that was outside of their remit (Beal, 2017). It might also be that due to their level of personal commitment, motivation, education or remuneration that they were unaware of how their institution may be lacking. Finally, it might also be that some institutions are very well resourced and managers are not lacking in any regard.

Finally, it can also be concluded from the comparison between responses in the UK and Irish surveys that FHE institutions in both countries experienced each of the same barriers when implementing sustainable ICT initiatives, albeit to different extents. Responses indicated a similarity between the two countries when attempting to be greener. Yet in other instances they had opposite views and this is likely to be because the majority of respondents in the Irish survey were ICT/IT managers and none were environmental/sustainable managers. The significance of these findings is that barriers to implementation of sustainable ICT initiatives exist in institutions regardless of geographical location (Allman, Fleming and Wallace, 2004; Wabwoba, Wanyembi and Omuterema, 2012; Wu, 2002).

**Impact of Research and How It Improved Practice.**

The impact of this research is the way in which it demonstrated the difficulties in implementing change for a more sustainable campus but also how those difficulties could be overcome. Ideally, institutions will ensure that stakeholders are fully engaged and committed, prior to implementing green ICT initiatives, as well as throughout the duration of the project. The aims of sustainable ICT projects should be made clear and communicated to all stakeholders with each participant understanding their role and the impact it has on the broader project. The effects of wasted time and public money will be highlighted and after recommendations are taken on board, significant carbon and cost savings will be made. This research also improved practice as its demonstrated the simplicity in creating an inexpensive webapp using an institutions’ existing ICT infrastructure. It also demonstrated why stakeholders may still not engage in its use despite its novel design and promise of a financial reward. Ideally this research should be read by university managers at all levels and responsibilities, as its application is multidisciplinary and outlines the importance of stakeholder engagement in greening projects across campus.
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Are dispositional mindfulness traits effective in sustaining pro-environmental behaviour?

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Abstract: Anthropogenic climate change and the destruction of ecosystems worldwide threaten to create irreversible and unpredictable environmental tipping points causing irreversible effects to many species, including our own. The search for sustainable solutions to these issues has led to the investigation of the role of mindfulness in supporting pro-environmental behaviours (PEB’s). Previous mindfulness/sustainability research identifies a strong correlational relationship between the practice of PEB’s and the existence of dispositional mindfulness, however, there is a clear gap in our understanding as to how and why mindfulness traits may become active during the adoption and sustaining of PEB’s. This study utilised the qualitative method of semi-structured interviews to investigate the lived experience of 9 participants committed to the long-term practice of PEB’s, and to identify if dispositional mindfulness traits were active in supporting them over time.

Thematic analysis identified that specific dispositional mindfulness traits (present-centred awareness, mindful intention, non-judgment, and nonreactivity) successfully combined with a pre-existing ecologically-focused worldview and environmental education/nature-connection experiences to create a sustained intention to lead a pro-environmental lifestyle. Participants utilised these traits to regulate their daily behaviours with a focus on: maintaining a present-centred awareness of the interconnected relationship between individual behaviours and negative environmental impacts, negotiating counterintentional barriers within their environment, and navigating negative psycho-social experiences that arise through the intention to act sustainably in an unsustainable society. These results suggest that promoting mindfulness practice can be an effective component in the adoption of PEB’s, specifically if mindfulness is taught alongside environmental education and nature connection experiences.

Keywords: mindfulness, pro-environmental behaviour, environmental education, nature connection, pro-environmental ethics.

Introduction

We are living in the Anthropocene; a situation where the collective actions of our species threaten to trigger irreversible and catastrophic climactic and ecological tipping points (IPCC 2014; Steffen et al, 2015). Despite decades of research we have failed collectively to make the necessary changes, highlighting the need for a greater understanding of how knowledge, awareness and ethics interact in how we think and behave in relation to the natural environment (IPCC 2000; Cairns 2001; Leiserowitz et al, 2005).

A significant part of the problem is that our lifestyles are increasingly fast-paced, time-poor and overstimulated, which increases reliance on fast, automatic and emotive forms of decision-making/behaviours that reduce cognitive processing time/effort (but also awareness of their environmental impacts), and societal cues/messages that offer behavioural guidance (but also susceptibility to their inherent values) (Bargh & Chartrand 1999; Kahneman 2003; Baron 2006; Neal et al, 2006). Together they contribute to a situation where daily behaviours are increasingly habitual/automatic, and guided by cues/messages that normalize unsustainable practices without consideration for their environmental impacts (i.e. habitual overconsumption, excessive use of resources, pollution and waste) (Brown & Kasser 2005; Dijksterhuis et al, 2005; Ohtomo & Hirose 2007).
Despite living in an unsustainable culture, there are individuals who have shown the awareness and intention to adopt and sustain pro-environmental daily behaviours (PEB’s), a process that could be supported by dispositional mindfulness (Rosenburg 2004; Ericson et al. 2014). Mindfulness is defined as a ‘moment-to-moment, non-judgmental awareness cultivated by paying attention in the present moment and as non-reactively, as non-judgmentally, and as open hearted as possible’ (Kabat-Zinn 2005 p.108). It is a mental construct that is both dispositional (Brown & Ryan 2003) and comprised of certain traits that could support PEB’s; (i) ‘present-centred awareness’ (PCA) to inner thought processes and daily experiences which helps to identify negative habitual/automatic behaviours and their impacts; (ii) ‘mindful intention’ to use PCA to support personal behaviour changes that enhance wellbeing for the self, others and all life; (iii) ‘non-judgmental’ acceptance of mental, embodied and environmental forces that shape experience, and (iv) ‘non reactivity’; becoming less reactive/over-whelmed by them, and responding with calm, thoughtful responses (Langer 1989; Kabat-Zinn 1990; Baer et al, 2006; Wallace & Shapiro 2006).

Although a relatively small body of research, there are studies that identify a strong correlation between dispositional mindfulness and PEB’s. Amel et al, (2009) and Brown et al, (2009) identify high levels of self-reported PCA in participants who perform PEB’s, leading to the suggestion that ‘mindlessness is incompatible with sustainable behaviour’ because PCA is necessary to be aware of the impacts of behaviours, the PEB alternatives, and to recognise/enjoy what we have instead of pursuing unsustainable consumption-based activities (Amel et al, 2009 p.21; Brown et al, 2009). Awareness of the environmental impacts of our behaviours does not however always guarantee the adoption of PEB’s, leading to the observation that a strong intention to change behaviours is also required (Baer et al, 2006; Amel et al, 2009). When investigating long-term PEB practitioners, studies have shown that mindfulness and pro-environmental ethics may combine to create this intention. Groups with established pro-environmental ethics (self-sufficiency back-to-landers (Brinkerhoff & Jacob 1999), simplified lifestyle practitioners (Brown & Kasser 2005) and members of The Buddhist Peace Fellowship (Jacob et al, 2009)) self-report high levels of PCA, established PEB’s, and strong nature connection experiences. It is suggested that PCA facilitates and mediates between the abilities to feel connected to the natural environment (through heightened nature experiences), to recognise their role in environmental degradation, and to identify alternative PEB’s. Together they create a pro-environmental ethical intention to change behaviours and the necessary awareness to know how and why.

The relationship between wellbeing and nature connection may also be significant as it has been shown that positive wellbeing is a pre-requisite for recognising issues larger than the self (i.e. environmental degradation and climate change) (Shah et al, 2012), with nature experiences supporting wellbeing by providing restorative physical and psychological benefits (Mayer et al, 2009). Howell et al, (2011) and Barbaro & Pickett (2016) have investigated this further and identify dispositional mindfulness as a significant correlate between nature connection and wellbeing, with PCA potentially heightening and intensifying the impact of nature experiences which in turn may lead to a strong physical and emotional connection to nature. Barbaro & Pickett (2016) speculate this may lead to the formation of ecological ethics and the intention to adopt PEB’s, but also that more research is required to move beyond the identification of positive correlates.

Collectively; the mindfulness/PEB research provides strong correlative evidence between PEB’s and dispositional mindfulness, pro-ecological ethics, nature connection and wellbeing. There is however a recognition that this evidence is reliant on self-reported
questionnaires which provide only a limited quantitative understanding as to how dispositional mindfulness may support the lived experience of sustaining PEB’s in an oppositional culture over time, especially in trait forms (Amel et al, 2009; Barbaro & Pickett 2016). In relation to this, there is a gap in the research as to the potential benefits of ‘non-judgment’ and ‘non-reactivity’; traits which are evidenced to support behaviour change in oppositional circumstances, specifically the ability to avoid over-identification and over-reaction to negative internal thoughts/emotions (Shapiro et al, 2006; Carmody et al, 2009), and the ability to navigate negative social situations through the development of an experiential knowledge base that enhances the ability to understand the impacts of their behaviour on those around them (including recognition of the uniqueness of individual situations, and people’s multiple perspectives) (Langer 1989; Fredrickson et al, 2008). In response to these limitations, the focus of this study is to provide long-term PEB practitioners the time and space to describe their lived experience of performing PEB’s in an oppositional culture with the intention to identify how and why dispositional mindfulness traits (PCA, mindful intention, non-judgment and non-reactivity) may support them.

**Methods**

An expert sampling strategy was used to recruit 9 participants who satisfied the following criteria; they were engaged in the long-term practice of PEB’s and had never practiced or received mindfulness instruction. Potential candidates were sought through an online invitation posted on pro-environmental social media pages. Candidates that satisfied the pre-selection criteria were asked to complete a supplemented online version of The Pro-Environmental Behaviours Questionnaire (PEBQ) (Markle 2013) compromised of 51 behavioural items spread across 6 pro-environmental dimensions; Domestic Conservation, Food and Drink, Domestic Products, Environmental Citizenship, Transport Use, and Energy Consumption. The threshold for selection was for each candidate to have practised 30/51 behaviours across the 6 dimensions for a minimum of 12 months.

The 9 candidates who satisfied this criteria were invited to participate in a one-to-one semi-structured interview of 90 minutes. Each interview utilised 4 open-ended questions to provide a standardised structure to the investigation; (1) Why did you choose to make sustainable changes to your lifestyle? (2) How did you implement those changes and sustain them over time? (3) What challenges have you faced and how did you overcome them? and (4) How do you feel you are making a difference? The interviews were recorded, transcribed, and then analysed using inductive and deductive thematic analyses to code repeated patterns of meaning within and across the set of interviews (see Holloway & Todres (2003). Coded data was considered at the level of sentences and paragraphs to maintain the integrity of the participant’s discourse and provided contextual information for each PEB. The identified codes were then systematically grouped into identifiable thematic categories; a process guided by the emergence of repetition of thematic concepts within and across the data. These themes were then used to develop a thematic map that provides the basis to investigate the relationship between dispositional mindfulness and PEB.

**Results**

A key finding of this study was the identification of two stages in participant’s experience of sustaining PEB’s; Stage 1 identifies the core experiences that led to PEB adoption, and Stage 2 explores the roles of dispositional mindfulness traits and ecological ethics in the ‘adaptive process’ of sustaining PEB’s in a society with systemic, psychological, and social barriers.
**Stage 1: Becoming sustainable is ‘a progression from unsustainable to sustainable’**

There were three core experiences that participants identified as having a formative role in their decision to adopt PEB’s; ‘formal environmental education’, ‘informal environmental life experience’, and ‘significant nature connection experiences.’ In terms of formal education; 8/9 participants (except Susan) had completed an environmentally-focused higher-education programme that developed awareness and understanding of the concepts of ‘interconnectivity’ (daily human behaviours have serious negative impacts on the environment), ‘interdependence’ (we need a healthy natural environment to survive), and their relationship to ‘sustainability’ (adopting PEB’s can help mitigate ecological crises). This understanding had been supported by ‘informal pro-environmental life experiences’ relating to; (i) ‘growing up in a pro-environmental environment’ providing positive learning activities in natural surroundings (all participants), access to environmental literature (all participants), and family discussions of anthropogenic environmental events (6/9 participants), and (ii) ‘exposure to other cultures’ with either normalised pro-environmental lifestyles (Ida, Julia and Jesse), or sites of anthropogenic ecological devastation that reinforced understanding of interconnectivity (Alice, Jesse and Amelia).

‘Significant nature connection’ represented an ongoing ‘special’ relationship developed by all participants since childhood. The natural environment was described by all as a special place that enhances wellbeing, both physically (e.g. hiking, swimming, running) and psychologically (e.g. relaxation, contemplation and stress relief). Participants recounted experiences of ‘happiness,’ ‘peace,’ ‘awe,’ and ‘freedom’ when in nature, and the ability to be ‘at peace with oneself and the world’, ‘to find oneself’ and the time and space to ‘contemplate larger than life issues’ (all participants). These experiences had led to all participants contemplating and caring for the state of the natural world and their role within it. Susan’s nature connection experiences are insightful as she didn’t enrol in an environmental education programme but still adopted PEB’s. At a critical stage in her life Susan decided to immerse herself in nature ‘to find myself’ through immersive ‘nature-based spiritual studies and experiences’. These experiences facilitated a desire to ‘live in reciprocity with nature’ and introduced her to the concepts of interconnectivity and interdependence, leading to the establishment of a rural crofting enterprise based on low-impact pro-environmental methods.

**Stage 2: Sustaining PEB’s is an ‘adaptive process’ supported by dispositional mindfulness and ecological ethics.**

When awareness, understanding, and strong nature connection combined, it created a desire to adopt PEB’s. This was an ‘adaptive process’ with certain interdependent themes; (i) an ethical imperative to ‘do the right thing,’ (ii) PCA of the impact of daily behaviours, (iii) an intention to sustain PEB’s, and (iv) a non-reactive and non-judgmental approach to counterintentional barriers.

*Ethics; a ‘collective moral responsibility’ to ‘do the right thing’.*

All participants agreed that their experiences at Stage 1 had led to the creation of a pro-ecological ethical moral compass with two guiding principles; (i) ‘do the right thing’ which was attributed to understanding and caring about their personal role in the developing ecological crises (i.e. their daily behaviours were contributing to the destruction of vital life-supporting ecological systems, and communities of human and non-human life), and (ii) ‘collective moral responsibility’ because these converging crises are caused by the ‘cumulative actions of the majority of our species’, and the effects will be ‘unfairly
distributed’ in space and time, disproportionately affecting human and non-human communities who have not directly contributed to the crises (all participants). When these were considered together it created an ethical imperative in the minds of the participants to adopt PEB’s. It is while sustaining this change that dispositional mindfulness traits were evidenced to become active.

Present-centered awareness and sustained mindful intention.
To adopt and sustain PEB’s, all participants described needing to be ‘deliberately conscious’ and ‘self-aware’ in ‘the present moment’ for two reasons; (i) to be aware of pervasive ‘unsustainable cues and messages constructed to manipulate their decision-making’ (i.e. to create a sense of lacking and unfulfillment which is resolved through the (over) consumption of low price, low effort, and high convenience products/services without consideration for the long-term social and environmental impacts), and (ii) to maintain awareness that everything they did has ‘a causal relationship to the environment’ in terms of ‘input>behaviour>output’ (i.e. every action they took whether it was consumption of products, resources, food or energy was supported by a range of input processes and produced a range of outputs, resulting in an ecological footprint). Each behaviour could either perpetuate unsustainable processes (extraction>production>consumption>waste), or they could ‘do the right thing’ and adopt a PEB alternative.

To initiate and sustain PEB’s all participants developed an ability to ‘collapse proximity’; a process combining PCA and sustained intention to overcome ‘the invisible layer’ between themselves and the ecological impacts of input/output processes. To collapse proximity participants discussed two techniques that made proximal connections visible; ‘enlightened consumption’ and ‘mastering the environment.’ ‘Enlightened consumption’ utilized PCA to ‘pay attention’ to salient production, processing and recycling information to guide PEB’s; (i) origin; to reduce transport miles, fossil fuel use, and support local businesses, (ii) contents; to identify unsustainable/hazardous materials/ingredients, (iii) trademarks; to identify pro-ecological/pro-social producers and processes, and (iv) supportive scientific literature; to identify and research eco-credentials and sustainable information to further understanding. This last strategy was particularly effective for energy consumption where the invisible layer was strong. Participants described learning the details of renewable energy generation (supplier websites, tariffs and literature reviews) and energy consumption (using online carbon footprint calculators), leading to high energy conservation (all participants), and the use of renewable energy suppliers now (6/9 participants) or planned for in the future (3/9 participants).

Food consumption was also described as having a strong invisible layer regarding the impacts of land management, deforestation, pollution and animal welfare. To enhance PCA, participants adopted two strategies; (i) getting to ‘know, trust and learn’ from key members of ‘the local sustainable food economy’ (7/9 participants), including experts at local farmers markets in urban environments (Ida, Jean, Alice and Ed) and local organic farmers and amateur food growing communities for those in rural environments (Jesse, Liz and Susan); and (ii) ‘self-guided research’ (all participants), with a sustained intention to learn from pro-environmental documentaries, social media communities, and environmental literature on the impacts of industrial agriculture (including factory farming, industrial fishing and the impacts of chemicals, fertilizers and pesticides), and ethical farming (i.e. organic, permaculture and community-supported farming techniques).

The strategy of ‘enlightened consumption’ was not always successful, with strong counterintentional barriers preventing its success regarding certain PEB’s. In response,
participants described a strengthening of their intention to control proximity through a long-term strategy to ‘master their environment’; a process that required learning new skill sets and negotiating setbacks. This was most evident in the intentional (re)design of the domestic garden as a multifunctional, pro-ecological space to navigate financial and accessibility barriers (esp; seasonal and organic produce), to provide healthy pesticide free food, and establish a healthy environment for wildlife (7/9 participants). Other examples included participant’s teaching themselves new skills to reduce household waste through the ‘repurposing, reusing and repairing materials’ (e.g. the use of old furniture and upcycled palettes to make raised gardening beds, bird boxes and cold frames (Ida, Ed, Jesse, Liz and Susan), and the repairing and repurposing of clothing (Ida, Alice, Amelia and Jean)).

Of particular interest was the extent to which ‘mastering the environment’ could be enacted when long-term intention, finance, and opportunity aligned. Two participants (Alice and Ed) were at the stage where they could afford to design and build a home that could support multiple integrated PEB’s. Alice was a key figure in establishing a pro-ecological housing cooperative which combined sustainable building materials (timber frame, straw bale and hemp), a cooperative food growing system, renewable energy supply (solar and solar heating), and an electric car. She described the process as a ‘massive undertaking’ akin to having a second job for two years but sustained the intention due to her ethical desire to ‘do the right thing’. Similarly, Ed was at the planning stage of designing his own pro-ecological home with the same sustainable interconnected materials and functions.

**Negotiating Counterintentional Barriers through Non-Judgment and Non-Reactivity**

All participants agreed that by trying to sustain PEB’s in an unsustainable society, they had encountered systemic barriers that challenged their ability to live by their ecological ethics, sustain PEB’s, and consequently, maintain subjective wellbeing. These challenges fell into three categories; ‘situational’, ‘financial’ and ‘time-based’. In terms of situational barriers, ‘transport restrictions’ proved to be a strong barrier in various ways; for those participants living and working in rural areas (Ida, Jesse, Liz and Susan) and/or who pursued rural nature connection activities (all participants), car use/dependency was especially high. The combination of ‘short length of vacation time from work’, ‘family living abroad’ and/or ‘close friends holidaying abroad’ also created a situation where most participants had chosen to fly in the past two years. ‘Living in a large urban environment’ was also highlighted as containing systemic barriers relating to a ‘lack of local recycling facilities’, and ‘access to fresh, seasonal, organic and/or local produce’ (Amelia and Jean), with ‘access to sustainably sourced ingredients and/or suitable vegan options in restaurants’ also highlighted (Jean, Ida and Ed). ‘Financial restrictions’ were also discussed in terms of ‘affordable ethical outdoors clothing and equipment’ (Ida and Ed), and specific items of ‘ladies clothing and undergarments’ (Ida, Jean and Alice). For 3 participants ‘time’ and ‘financial barriers’ combined to impact on their ability to upscale their ethical food growing intentions’ with Jesse having a young family restricting time and budget, and Liz and Susan’s plans to establish a pro-ecological crofting enterprise experiencing restrictions leading to the hiring of fossil fuel-based landscaping machinery.

A common theme related to all barriers was the experiencing of an ‘adaptive process’ of learning to ‘not beat myself up.’ Each participant discussed having the PCA to know when they were enacting an unsustainable behaviour and its impacts. This led to negative psychological and emotional experiences (i.e. ‘sadness’, ‘depression’, ‘feeling a failure’ and ‘anger’) for all participants. However, over time, each participant explained the same rationalization process that drew upon the ability to be non-judgmental and non-
reactive towards the self. This evolved from learning to ‘see the bigger picture’; specifically, that counterintentional barriers were deeply systemic and reflective of the values of the oppositional culture they lived in, and so reacting negatively to these situations had proved counterintuitive. Instead participants discussed learning to recognize when they were ‘doing their best’ and to treat themselves ‘gently’ and with ‘compassion’. This resulted in being able to navigate these negative experiences while strengthening their intentions to sustain the PEB’s they could. ‘Mastering the environment’ was discussed within this process as a long term strategy to reduce the frequencies in which they encountered counterintentional barriers if and where possible.

This ‘adaptive process’ of ‘introspection>rationalization>compassion>acceptance’ also had a social dimension, with all participants experiencing negative social situations in relation to sustaining PEB’s. Participants explained that they often felt ‘outside of normal culture’ because of their views and practices (especially during the early phase of adopting PEB’s), and felt ‘challenged’ or ‘misunderstood’ by close friends and family. This often led to ‘heated conversations’, ‘arguments’ and feeling that they had to ‘defend or justify themselves’, closely followed by feelings of ‘anger’, ‘disappointment’, ‘depression’ and ‘loneliness.’ Realizing that this led to negative psychological and social wellbeing, participants described an adaptive rationalization process involving ‘stepping back’, ‘recognizing the other person’s point-of-view’ and ‘seeing the bigger picture’. This was identified as a period of ‘heightened awareness’ where they learned to see ‘the uniqueness of their situation’. (i.e. participants realized their ethics and PEB’s were created through a privileged situation; they had been fortunate to engage in environmental education and meaningful nature connection experiences which had taught them the complexities of interconnectedness and interdependence). A result of this cognitive process was the decision to adapt and approach negative social circumstances with ‘heightened awareness’ and ‘non-judgment towards others’ (all participants). This was not a simple or easy situation to negotiate as participants recognized the severity of the environmental situation and the urgent need for environmental and social change, but they also understood that passing judgment and reacting negatively to challenging social situations could be counterintuitive, especially in terms of psycho-social wellbeing and positive social relationships. Instead the decision taken by all participants was to help others understand the severity of the situation by ‘leading by example’ and facilitating opportunities for ‘environmental education’ wherever possible.

This approach created interesting spillover effects in the lives of the participants with the promotion of PEB’s becoming part of a larger professional and community-focused educational direction. Amelia is currently training to deliver community-focused ecological mine remediation in developing countries, Jean is developing low impact environmental management strategies for large-scale public events, and Liz and Susan are launching a pro-environmental crofting enterprise open to the public with an accompanying educational social media webpage. Environmental education had also become a focus for certain participants in their social lives with Ed (recently retired) in the process of learning to be lead volunteer for a sustainable development charity geared towards teaching PEB’s to local schools and communities in developing countries. Julia is in the process of creating a community-focused sustainability group to disseminate knowledge and experience to help support others adopt PEB’s and learn techniques to ‘master their own environment.’ Jesse has responded to the reduction in nature connection time because of having a young family, by dedicating his spare time to creating a pro-environmental permaculture-based food
growing garden which he will use as an educational site for his children to learn the principles of interconnection, interdependence, and the importance of sustainability.

Discussion

By investigating the common experiences that led to the adoption of PEB’s it was possible to understand how and why unsustainable behaviours were brought back into conscious awareness and changed (Stage 1). Formal and informal environmental education experiences developed knowledge, understanding and awareness of anthropogenic environmental impacts and their relationship to personal daily behaviours (interconnectivity and interdependence), while strong nature connection experiences added a significant emotional dimension of caring strongly about the consequences. Together they interact cognitively and emotionally to create a non-negotiable pro-environmental ethical imperative to ‘do the right thing’ and adopt PEB’s (Stage 2). This is insightful as it addresses the correlation identified between awareness of environmental degradation, positive nature connection experiences, and likelihood to harm the natural environment (see Brown & Kasser 2005; Dutcher et al. 2007; Jacob et al, 2009) by exploring how specific lived experiences interact to catalyze pro-environmental change in an individual.

This does not however explore how PEB’s are sustained over time in an oppositional culture. High dispositional mindfulness has been identified as a strong correlate in supporting behaviour change (see Chatzisarantis & Hagger 2007; Levesque & Brown 2007), but the relationship has yet to be fully explored in relation to specific mindfulness traits and adopting/sustaining PEB’s (Amel et al. 2009; Barbaro & Pickett 2016). The strategies utilised by participants are therefore insightful. Central to their success was the ability to intentionally act as an active and aware agent at the present-centre of the causal relationship inherent to unsustainable behaviours (i.e. input>behaviour>output) repeatedly across a range of PEB’s. A significant aspect of this involved learning to recognise and overcome the ‘invisible layer’ that separates a behaviour from the environmentally damaging input/output processes that enable that behaviour (enlightened consumption). To do this participants developed a network of situation-specific PCA-enhancing strategies that enabled proximal connections to be made between behaviour and input/outputs (reducing proximity); ranging from the use of salient information provided at the point of performance, autonomous and intentional research practices to fill information gaps, and the intention to locate informed/supportive individuals and specialists within their environment. Together these strategies removed the invisible layer, replaced it with informed knowledge of processes and impacts, thus enabling PCA of their active role in this situation and facilitating the intention to make pro-environmental choices.

The instances where participants encountered strong counterintentional barriers to controlling proximity are also insightful. As a response, participants described a strengthening of the mindful intention to ‘master their environment’; a strategy that offered interesting short and long term benefits. In the short-term, the sustained intention to learn new skills (including the ability to overcome mistakes, and experiment to find successful solutions) brought certain inputs/outputs under direct control within the domestic environment, while in the long-term it represented the intention to learn how to design and build a domestic environment that would enable multiple interconnected PEB’s across all dimensions to become normalised (i.e. sustainable building materials, renewable energy generation, storage and use, electrified transport, and organic pro-ecological food production). A key factor was the acknowledgement that high levels of sustained awareness
and intention were required to engage in such a long-term project. An interesting spill over
effect of learning to master their own environment was that it also primed participants for
the opportunity to become an educator in their communities to deliver this knowledge and
skills to others to promote a wider uptake of PEB’s.

Another area in which dispositional mindfulness supported the practice of PEB’s
involved the traits of non-judgment and non-reactivity in supporting psycho-social
wellbeing. Psychological wellbeing has been identified as an important mediating factor in
the ability to sustain awareness of ‘larger than self’ environmental issues (Shah et al. 2012),
and the practice of PEB’s (Howell et al, 2011; Barbaro & Pickett 2016; Prati et al, 2017).
Multiple studies have also shown that individuals who live a lifestyle in line with their pro-
environmental ethics, self-report high levels of subjective wellbeing (Brinkerhoff & Jacob
1999; Brown & Kasser 2005; Jacob et al, 2008). The experiences of participants in this study
however offer a more complex relationship by exploring how the intention to support PEB’s
can threaten to lower psychological wellbeing, and how non-judgment and non-reactivity
can be important mediating factors.

All participants reported that they had encountered strong counterintentional
barriers that they were unable or unwilling to negotiate at specific times (i.e. short vacation
times from work, family members living overseas, lack of public transport in rural areas,
ability to access/afford sustainable options in relation to products or services), leading to
the performance of unsustainable behaviours. Participants acknowledged that they had not
been ‘forced’ to perform these behaviours and were aware of their environmental impacts,
but also that their desire to be with close family members and/or friends, pursue important
outdoor interests (including nature connection), and purchase specific products were
deemed to also be of importance. This highlights the complexity of trying to live sustainably
in a society with normalised unsustainable practices/systems; at times ethics and PEB’s may
become compromised in the pursuit of certain positive experiences, which can have lasting
negative psychological consequences. When reflecting on the impacts of these
compromises, participants described experiencing negative emotions (guilt, anger and
depression) and self-judgments (feeling a failure) that lowered psychological wellbeing.
Over time however participants described an ‘adaptive process’ of ‘learning to take a step
back’ and ‘seeing the bigger picture’ by acknowledging and accepting that 100%
sustainability was still beyond their reach, that they lived in a society with strong systemic
barriers, and that there would be times where they may fail. As a response, participants
gradually learned to ‘not judge myself’ and ‘not to beat myself up’ by avoiding ‘negative
spirals of thought’ and (re)focusing on areas they could control (especially ‘master the
environment’). This was not perceived as an excuse to justify the performance of
unsustainable behaviours, but as a strategy to maintain long term positive psychological
wellbeing, sustain the intention to perform PEB’s within their control, and/or learn new
skills for future adaptation (master the environment).

This adaptive strategy is significant as it highlights the demands of sustaining PEB’s in
an unsustainable society. If participants had to learn to adapt and evolve non-judgmental
and non-reactive strategies to live by a pro-environmental ethical code, then this may be
beneficial to incorporate into future environmental education practices. There is evidence
to support this in studies where clinical patients receive mindfulness training; patients
describe developing an ability to utilise non-judgmental and non-reactive approaches to
challenging circumstances to avoid negative spirals of thought, maintain positive
psychological wellbeing, and sustain the intention to make positive long-term behaviour changes (Kabat-Zinn 1990; Ma & Teasdale 2004; Shapiro et al, 2006; Carmody et al, 2009).

Of particular interest is the positive benefits a mindful disposition can have on social relationships and interpersonal wellbeing. Studies focusing on the impact of mindfulness practice in social situations show that a non-judgmental and non-reactive disposition can also enhance a person’s sensitivity to the unique context of a specific situation, and the ability to recognize multiple perspectives within those situations (Langer 1989; Chatzisarantis & Hagger 2007). This reflects the experiences of participants in this study who had to learn to negotiate negative social situations as a result of the ethical imperative to ‘do the right thing’ being a ‘collective moral responsibility.’ All participants described situations where close family and friends were either performing unsustainable behaviours in their presence and/or challenging the participants themselves for advocating and performing PEB’s. It was during these situations that a non-judgmental and a non-reactive disposition was identified as a way of negotiating the friction between knowing anthropogenic impacts on the environment require an urgent collective effort, and being in the presence of close friends and family who were contributing to the problem, often with little awareness of the impacts of their behaviours.

In a similar process of learning non-judgment and non-reactivity towards the self, each participant recounted an adaptive process of learning to ‘take a step back, see the bigger picture’ and ‘contemplate the other person’s point-of-view,’ specifically the awareness that they themselves had adopted their ethics through environmentally-focused education and nature connection experiences which they acknowledged was not a common experience for their family and friends. In addition to this, there was also an awareness that their family and friends were living what was accepted as a normal life within a society of normalized unsustainable cues and messages, and that many of these behaviours had an ‘invisible layer’ between action and consequence. With this in mind, participants realized that a judgmental approach had only served to alienate when their goal had been to promote the practice of PEB’s. In response to this each participant had arrived at the same conclusion; that the only way to help promote PEB’s at both the individual and collective level in their social environments, was to ‘lead by example’ and ‘to educate those around them’ without ‘judgment’ and by being ‘polite’, ‘patient’ and to act with ‘compassion.’ The ultimate goal was to empower those around them to believe that they can make the necessary PEB changes themselves, master their own environment, and to be supportive in those challenging and difficult times that the participants themselves had encountered.

Conclusion

A qualitative thematic analysis of the experiences of 9 long-term practitioners of PEB’s has identified two key interconnected features of sustaining PEB’s over time; (1) significant nature connection and formal/informal environmental education experiences led to formation of an ecological ethical imperative to ‘do the right thing’ and adopt PEB’s, and (2) the dispositional mindfulness traits of present-centred awareness, intention, non-judgment and nonreactivity are effective in sustaining long-term PEB’s. The traits of present-centred awareness and sustained mindful intention facilitated the ability to maintain a present-centred awareness of the unsustainable/invisible aspects of a daily behaviour, and support the adoption of sustainable alternatives (including ‘mastering the environment’). While the traits of non-judgment and non-reactivity helped mediate psycho-social barriers to maintain
positive wellbeing, understand alternative point-of-views, and support the long-term intention to disseminate environmental education in their communities.

The small sample size of this study limits generalizability, however the number of instances where dispositional mindfulness traits were effective across the range of PEB’s leads to the recommendation that the role of dispositional mindfulness in supporting the sustained practice of PEB’s should be investigated further. This should continue to utilise the qualitative methods of semi-structured interviews and thematic analysis as this addresses a significant gap in the literature; the majority of mindfulness/sustainability research is quantitative and reliant on self-report questionnaires. Although this has identified a strong correlation between dispositional mindfulness and PEB’s, it does not explain how dispositional mindfulness supports the daily lived experience of the PEB practitioner.

The continuation of the global ecological crisis and the lack of real change at a global level only serves to increase the likelihood of the triggering of irreversible climactic and ecological feedback loops. The shift in focus to community-level sustainability education and mitigation/adaptation strategies is likely to be essential and urgent in the coming years. The results of this study have shown how independent self-determined individuals have sustained PEB’s in an oppositional culture, and how dispositional mindfulness has supported this. The roles of environmental education and nature connection have also proved to be significant. As practitioners have displayed, this experience promotes a desire to educate others in their social environment. The key strengths of mindfulness-based education, environmental education and the promotion of nature connection experiences is that they are free and accessible across a range of demographics (i.e. age, income, background) if there is a strong community hub. The intentions of Barrett et al. (2016) to establish a free and accessible Mindful Climate Action education curriculum is an example of how this could be implemented, with the results from this study contributing to a guide of how mindfulness can assist in this mindful climate action paradigm.

References


New Territories: Digital Materiality from Natural systems to Environmental Impact

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Abstract: Digital fabrication, between advancements in software, simulation, and machinery, is pushing practice today towards more complexity in design, allowing for unparalleled explorations. Yet at no time have questions of material knowledge become more relevant and crucial, as technological advancements approach a radical re-invention of the design process. As more designers look towards tactile crafts for material know-how, a parallel interest in natural behaviors has emerged trying to embed environmental performance into the designed objects. New Territories, a yearly architecture and design course on digital design and materiality, allows students to explore processes of digital fabrication in intersection with environmental behaviors and hands-on material experiments. The aim throughout the course is to explore the design of building systems, such as modular facades, intelligent cladding, or adaptable seating, by embedding current digital technologies with an understanding of the environment and physical material behavior. This paper will highlight the importance of learning from nature and physical material explorations to design these active and sustainable systems. It will detail the work done over the course of three years, on themes of building behaviors, environmental responsiveness, concrete plasticity, and material composites. Through the work, the paper will elaborate on the design process, describing the different material experimentations, digital and analog methodologies, and the final results. It will shed light on the persisting importance of material knowledge in intersection with advanced digital fabrication, and the significance of learning from natural systems and bio-properties to embed an active performance in today’s design process.

Keywords: digital design, digital fabrication, materiality, environmental behavior, building materials

Introduction

In today’s digital age, the proliferation of advanced technologies, namely those associated with prototyping and three-dimensional fabrication, has allowed unparalleled investigations of form, material, and making, right from the individual designer’s desktop. This has democratized the production of physical prototypes, allowing any individual to easily access the technology and grasp its process. This has also had a major impact on architecture and the production of space, as designers move towards more computerized production techniques.

Digital fabrication, or the process of making via a digital interface, is however necessitating a clear understanding of material behavior and technological constraints, and thus informing the design process along the way. In addition, it is generating for many designers an aim to produce active and productive prototypes, and compelling them to look at natural systems as a reference to generate environmentally relevant outcomes. In the advent of a digital world, an inherent interest in the ‘analog’ and the ‘organic’ is somehow embedding itself in the work of many designers. This paper will address these different notions informing the practice, from materials and crafts, to natural references and digital fabrication methods, presented through the work of the New Territories seminar course, and its student projects’ outcomes.

Learning from Nature for the environment
The natural environment has evidently been the essential model upon which architecture, the man-made environment, has long been shaped and formed. According to Petra Gruber (Gruber et al, 2011), biomimetic design, or design modeled from natural systems, has existed as long as architecture existed itself, from the cave dwellings to early translations of natural systems to form the built environment. However, she differentiates between bio-inspired design and biomimetic design, where the latter differs through its concern with the embedded systems and inherent logic within nature, rather than its formal or aesthetical aspects. Such a relationship in biomimetics between architecture and nature is crucial, and in the current digital world, a renewed consideration for nature, its systems, and their complexities, seem almost evident.

With the advancements in intelligent technologies, a deep understanding of natural systems and their inherent behaviors is fundamental to design environmentally active and conscious products. Brownwell and Swackhamer in Hypernatural’s book introduction (Brownwell et al, 2015), talk about a changing paradigm in today’s design world, where a shift is happening from understanding nature as a binary opposite to the man-made world - as an environment that needs to be controlled and that opposes technology - to recognizing it as an extension of the built habitat and with a mutual influence from and on technology. They go on to state that “The ultimate aim of technology is not anti natural; it is hypernatural. It involves working directly with natural forces and processes- rather than against them-in order to amplify, extend, or exceed natural capacities. This approach characterizes many fields of human industry today, including science, engineering, architecture, and art, which are infused with a growing enthusiasm and reverence for nature.” Furthermore, the accessibility to advanced software and fabrication techniques has given architecture the capacity to model complexities and behaviors found in nature, whether formally or as digital simulations. According to Branko Kolarevic (Kolarevic, 2003, p.1-16), “digital technologies are changing architectural practices in ways that few were able to anticipate just a decade ago ... Digitally-driven design processes, characterized by dynamic, open-ended and unpredictable but consistent transformations of three-dimensional structures, are giving rise to new architectonic possibilities”.

Accordingly, and in considering the design disciplines today as having the responsibility to produce outcomes with positive environmental impact, and given the allowances digital technologies are giving the designer today, it remains imperative to look at nature for reference, not only to enable us to maintain it, but also to learn from it to produce intelligent, productive, and environmentally relevant prototypes.

**Digital fabrication and Digital craft**

Digital fabrication today has become a crucial means of production, allowing the direct application of a three-dimensional digital file into a physical prototype. Through various technologies, such CNC routers (computer numerically controlled machines) or 3D printers, it has transformed the ways in which designers, or individuals at large, produce physical objects, moving the means of production from the factory or the specialized workshop, right into the designers’ desktop, more so with the proliferation of low cost technologies. The open source digital world has enabled a worldwide sharing of knowledge and material know-how, allowing the quick advancement of digital fabrication within and outside of the design field. Furthermore, digital fabrication today is necessitating the role of the designer as both the thinker and the maker, enforcing an understanding of the technology and the material constraints within the design process. Dimitris Papanikolaou (Papanikolaou, 2012) links such
technological constraints to design conception and states “Digital design and fabrication have significantly affected professional practices, as the designers of complex geometric assemblies must holistically take into account the machine, material, and computational constraints during the design process.”

This hybrid of the designer/maker has brought forth the notion of the digital craft, linking that digitalized design forming process to a crafts inspired process of making. In his text ‘The Risky Craft of Digital Making’, Branko Kolarevic (Kolarevic, 2008) gives significance to this notion of the ‘digital craft’, by referring to Malcolm McCullough’s (McCullough, 1996) definition of the term as “an emerging set of material practices based on digital media that engage both the eye and the hand, albeit in an indirect way.” He proceeds to define several key attributes to this new craft, such as the embedding of material understanding in the digital design process, the linking of the hand and the mind in the fluid form making workflow, the iterative process of testing prototypes in various models, and the circular feedback between the physical prototype and the digital file. In that, he relates the traditional understanding of crafts as an art relying on a hand-mind relationship, on material know-how, and varied iterations, to the current digital design and fabrication process. Kolarevic (Kolarevic, 2003, p.46-87) furthermore proposes that a new materiality is taking shape in the architecture and design practices, as technology and complex forms are inspiring novel investigations in materials, with new composites, intelligent, and active properties.

Consequently, this enforces the importance of not only the digital counterpart in the design process but also, and more significantly, the physical and material parts, enriching the process with a back and forth move from the digital to the physical. The methods of physical testing, trial and error, material understanding and know-how, become essential within the design process as parallel and symbiotic resources to the digital forming process.

Process & methodology

The above two approaches, from digital craft and its process of making, to learning from natural systems and models, have equally formed the framework within which the architecture seminar New Territories is given yearly at the Department of Architecture and Design, at the American University of Beirut. The course is offered as a technology research-based elective, where senior undergraduate architecture students are given the chance to advance their technical and digital skills, and to explore material systems through making. In New Territories, the approach has been to investigate this analog/digital process as relevant to the undergraduate level in architecture, with a parallel interest in producing building systems that have a productive environmental impact. Starting with natural systems as reference for environmental concerns, the students were asked to design prototypes and explore materials with the aim of creating building systems that would generate a positive environmental effect on the built environment. They had to involve hands-on tools, understand the materials they are working with in depth, and to utilize digital fabrication methods and digital models, to produce accurate design outcomes. As such, they focused on the continuous crossing between hands-on material explorations and digital iterations, using research and trial and error methods, to produce their inventive prototypes.

Each year, the course focused on a different project theme, however it constantly revolved around exploring the design of building products or active building systems, be it modular facades, intelligent cladding, or adaptable seating. And this was framed and approached every year by embedding current digital technologies with an understanding of natural systems and a physical know-how of material behavior. The aim however was never
to reach a designated solution but rather to allow for open-ended explorations. The learning happens as such in the process itself rather than in the end product.

From these different aims, three main themes of inquiry emerged through the varied explorations across the three years, each one approaching materiality and digital technologies from a different lens. The first lens focused on intersections of nature, craft and digital techniques to form active façade systems that respond to environmental constraints. The second lens involved the plasticity of concrete material, fluid formwork and natural systems, to design urban seating. The third lens focused on concrete composites to produce various cladding and tiling prototypes with direct environmental impact.

New Territories – experiments 1

The first year and theme focused on the design of intelligent façade assemblies, through crossing the study of natural systems as precedents with traditional crafts methods. The students worked on designing performative façade systems, each group starting from the study of a relevant natural system and a specific craft, and then using parametric modeling to develop their modular facades. They looked at jellyfish, dandelions, and silk worms to design behavioral modules that responded to sun, visibility, and wind. They utilized hands-on experiments and digitally produced prototypes, to optimize their designs.

In studying the dandelion, one group of students were interested in the structural aspects of the dandelion’s geometry and its connection to wind and ventilation. They looked at it as a reference for a modular façade system of assembly that allows cross ventilation and varying shading opportunities. The geometric analysis of the dandelion was then followed by parametric digital modeling, guided by ventilation and sun orientation constraints, to produce the façade’s design. The students studied in parallel the craft of weaving to develop the interlocking parts, and accordingly designed an open three-dimensional grid system, with varying openings and axes for cross ventilation and sun protection. To produce their final prototype, their focus was on integrating new fabrication techniques in an optimized manner; Rather than produce the entire space-grid through digitally fabricated techniques, they opted to only produce the more complex connecting joints between the different units with high resolution 3D printing, while using market available rods to form the simpler connecting members. (Figure 1)
New Territories – experiments 2

The second theme looked at the cross of craft and digital technologies through form-finding techniques and material properties, bringing in flexible formwork into the digital fabrication process. In groups, students explored concrete plasticity and behaviors with natural references, as they worked on the design of an exterior urban seating installation using lightweight concrete composites and casting methods. Themes of concrete casting, plasticity, and form-finding techniques, inspired by works of Antoni Gaudi and Frei Otto, highlighted the role of hands-on experiments, composites, and fabric formwork in producing plastic and elastic material qualities. The seating, designed for an outdoor area on the university campus, was required to accommodate several users and various modes of sitting. Two groups formulated two main approaches to the semester. The first one utilized form-finding techniques by applying tension on a stretched fabric to produce the design, and the second group utilized a natural system to create and cast a topographic seating prototype.

In the first approach, students experimented with fabric and casting at various scales, highlighting the role of tension, gravity, and materiality for form-finding and design intervention. They focused on creating centralized zones of depressions and mounts, moving between structural requirements and seating configurations. Their surface provided centralized meeting zones for seating. In parallel, they worked on concrete and plaster
composites, with acrylic and resin admixtures and reinforcing fibers, to produce various material tests ranging in strengths and plasticity. Their material studies allowed them to move up to a real-scale installation, using fabric-formed concrete method, to cast their topological seating design. (Figure 2)

In the second approach, students were interested in the turtle shell as a modular hexagonal structure, where material, form, and structural integrity are interrelated. After geometric and formal analysis of the turtle shell system, they formed a modular hexagonal system of their own, where variations in the top surface of the hexagonal unit created a varied seating position. Their material experiments focused on variations of textures and elastic qualities of the concrete and plaster pours, using stronger mixes for lower pours, and more elastic mixes, enabled by the use of acrylic, for top layers. The formwork was CNC milled in wood and lined with acrylic sheets to form the hexagon’s sides, with the seating surface milled in extruded polystyrene foam, to provide a textured finish. In their mixes and pours, the students worked with lightweight materials such as foam spheres and inflated balloons, to hollow the body of the concrete seating and decrease its weight. (Figure 3)
New Territories – experiments 3

The third theme focused on bio-composites and material experiments, working primarily with concrete mixes, and using digital fabrication techniques to create performative cladding or tiling systems that respond to environmental concerns. The interest was mainly in addressing critical urban and environmental issues through these architectural building materials, and to bring awareness to the imminent problems of waste, pollution, and other local crises. Several issues and contexts of interest emerged and became the center of the students’ research.

As a methodology, students began by investigating their issue, while looking at precedents and material composites that have addressed similar concerns. They were required to work with modular systems that can adapt to various situations and enhance actively their immediate environment. The different groups of students experimented with concrete composites, relying on material research, parallel case studies, and physical hands-on trials, to produce different cladding and tiling prototypes. Within the work process, clay 3D printing was integrated, as a fluid method of additive prototyping that involves the layered pouring of soft clay to form three-dimensional outcomes. The process of clay 3D printing played a major role on some students’ projects as a formative agent for their design and its potential application.

The first group was interested in porous concrete pavers as a system that allows water infiltration into the natural ground, reduces water run-off in urban streets, and includes rainwater collection for irrigation needs of urban green surfaces. Their design was developed as a smart urban paving system that integrates seating and walkways along a widened pavement area in Beirut, and includes green zones and water collection system. It was envisaged as a smooth surface with varying dips and hills, formed by a modular triangular grid, with the modules prefabricated and assembled together on site, replacing existing urban pavers. The students experimented with various mixtures of concrete, using lightweight and foam-based aggregates of various sizes, and produced a series of potential compositions. They utilized clay 3D printing as a tactile “craft” method for real-scale fabrication, learning...
from its textured results and the varying degrees of porosities and surface qualities that emerge as a result of the additive layering of fluid clay. The design of their modular prototypes therefore integrated this fabrication and material porosity to enhance the water infiltration performance of their urban paving system. (Figure 4)
The second group also reflected on the urban streetscape, but focused their research on areas around main traffic arteries with large concentration of pedestrians and public activities. Their interest was to create a system of urban cladding that can reduce air toxins and car-generated pollution at the pedestrian street level, and accordingly focused on the area around Beirut’s corniche, to design composite cladding integrating concrete and natural moss. Their research expanded on work done by BiotA Lab at the Bartlett School of Architecture in London, and referenced the latter’s experiments in composites of concrete and moss; the moss actively helps by absorbing air pollutants in its vicinity, in addition to producing oxygen. The students further looked at aerated concrete techniques and experimented with additives to create lightweight pockets in the pour, while adding phosphate magnesium to lower the PH level of the concrete mixture, and thus allow for better moss growth. Their resulting design was informed by the naturally occurring geometry of the voronoi cell, creating an urban wall system with pockets and cavities of varying sizes, which allow higher water capture at the base and enhance the growth of urban moss. (Figure 5)

A third group was concerned with the refugees’ crisis in the Bekaa valley and the growing need for immediate protective shelters that can withstand the harsh weather
conditions in the Bekaa. Some of the main issues that students wanted to address in designing new forms of shelters were issues of durability, comfort, security and cost efficiency. Their investigations began by looking at modular lightweight concrete blocks, and their interest was to design a new block type that can generate the shelter’s form and provide high efficiency in its construction.

Through research, the students became inspired by the traditional Musgum mud huts from Cameroon, which are conical shaped dwellings with an inherent structural capacity and an insulating thick wall. They researched further the formal and structural aspects of the huts, linking them to catenary arches and shell structures found in nature. Their design elaborated on this conical form, and resulted in a dome like shelter with a central top opening for ventilation. A tessellated pattern was projected on the dome, and formed the base grid for the modular block system. The new “hut” would be fabricated from the resulting diamond shaped blocks, stacked above one another with a locking compressive joint. To produce these blocks, the students experimented with various mixes and composites of concrete, trying to reduce the heavy aggregates in the mix and to replace them by lightweight alternatives. They were specifically concerned with different types of waste materials, such as wood saw, wood bark, and plastic fibers, as potential additives for reinforcing the concrete. Their interest was to integrate waste in an up-cycling strategy, reducing cost and increasing the efficiency of their modular blocks. Their different material experiments produced a variety of potential composites with different block weights and consistencies. (Figure 6)
Learning & Outcomes

In the course, and over three sessions and three variations of digital/analog experiments, multiple learning outcomes came across. The back and forth process between digital iterations and physical prototyping allowed students a rich understanding of the different constraints at hand, and integrated a direct understanding of material within their design approach. Issues such as the behavior of concrete, its weight, the process of its hardening, the appropriateness of certain types of aggregates, and the constraints in forming the formwork for the pour, all enabled a rich and hands-on process that informed the design at different stages.

Furthermore, the integration of advanced fabrication techniques enabled the students to proceed into more complex formal applications, utilizing 3D printing and CNC milling at intermediary and final prototyping stages to test and optimize their shapes. In the course of three years, the different student groups approached the environmental issues and the concern with natural systems from varying points of entry. The earlier approaches were interested in nature as a parallel system of reference, one that can become an exemplary formal model to inspire their own designs. In later experiments, students were more interested in direct hybridity between natural systems and their material experiments, integrating material behaviors, bio-composites, and chemical reactions, to form their active products. Their concern with traditional and crafts methods of making was also varied, from looking directly at a craft technique to converting their own making process into a digital craft.

In a way, the course pushed the students to consider an environmental and design problematic in an open-ended fashion, to approach it as an opportunity for experimentation rather than as a problem-solving endeavor. The gained know-how in both digital and physical methods of making, with all the associated constraints and results, was more integrated within the process itself rather than in the final outcome. The hope was to give the students the opportunity to gain innovative and thorough understanding of the correlation between environment, materials, technology, and design.

Conclusion

This paper thus details the pedagogical and design methodology developed by the research seminar New Territories through its students' experiments over three years, elaborating on their material experimentation, digital and analog design methodologies, and final results. It aims to shed light on the persisting importance of material knowledge as it intersects with advanced digital fabrication, and the significance of learning from natural systems and biological properties to embed an active performance in today's design process. It projects forth an essential responsibility on the new generation of designers to address critical
environmental issues through design, and to benefit from advancements in technology and the design field at large to push the boundaries of making. With the abundance of digital fabrication techniques however, continuous awareness of the tactility of a material process is crucial for the designers of today, and is strongly needed to push forth critical and informed results in design.

References


Teaching about Nearly Zero Energy Buildings in the Architecture curriculum in Havana, Cuba

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Abstract: Nearly Zero Energy Buildings paradigm is changing the way buildings are designed worldwide. In order to have professionals more prepared to face this goal a design workshop has been implemented for Architecture students at the Technological University of Havana, Cuba. In this paper the background of the environmental design and teaching of nearly zero energy buildings in the architecture curriculum of Havana is explained. The objective of this paper is describe an academic experience with transdisciplinary and integral program designed in order to optimize building’s energy use. From the program consist of a main subject of architectural design, elective and optional subjects, and professional practice. The main subject consisted of architectural design of buildings in urban and rural contexts. The optional subjects were directed towards renewable sources of energy, participation and social impact and the principles of bioclimatic design in hot-humid contexts. The professional practice was aimed at diagnosing energy consumption of different buildings types in real contexts. Finally, the paper discusses the main results and lessons learned from experiences with this educational program through different study methodologies such as historical analysis of sustainability in architecture studies of Havana in last 40 years, presentation of transformations made to program of subject in last two courses as well as exhibition of some results by student work carried out in different contexts.

Keywords: Nearly Zero Energy Buildings, Architecture Education, Havana, Sustainable design, Passive design, low energy design

Introduction

Cuba, as almost all countries, is committed to reduce the negative impact of human activities on the environment, based on agreements within The United Nations Framework Convention on Climate Change as The Paris Agreement. The high CO2 emission on the island is mainly related to the high use of imported fossil fuels as main energy carrier to generate electricity. Furthermore, according to SIELAC-OLADE (“SIER,” 2005), major energy consuming sectors in Cuba are linked to the built environment: residential (49%), industrial (27%), as well as commercial and public services (20%).

In the country there is a political willingness to diminish the energy use in buildings as well to increase renewable energy generation. One of the first important actions was the so-called “Energy Revolution” in 2005, intending to decrease energy demand in residential sector, by changing to more efficient appliances. Another goal officially recognized from 2016 in the "National Plan for Economic and Social Development until 2030", is to meet 24% of the energy demand by using renewable energy sources (RES). In order to increase the use of RES from the current share of 4% to this 24%, main investments will be located in bio-electricity from sugarcane, solar fields and wind farms. Currently, the decree-law "Renewable energy development and energy efficiency" is under discussion, which should allow the use of RES and
other technology to improve building energy efficiency. Furthermore, since 2014 the energy license that approves compliance with the requirements of the energy efficiency standard in the architectural project is established. Regardless of these policies, the building sector is not changing as fast as needed. The current strategies for building energy saving mainly focus on saving costs and materials, and so far a comprehensive policy to improve the energy efficiency of buildings has not been determined.

The European Union has declared (Directive 2016/0382) the intention to achieve for 2030 at least the 27% of energy shared by RES, and it also defined even biggest goals for 2020 to some countries that already have higher use of RES. In parallel to this regulation, the EU has a greater aspiration, by defining in the Directive 2002/91/EC and its recast Directive 2010/31/EU that for 2020 all new building will be nearly zero-energy building (nZEB) what consist on "a building that has a very high energy performance and the very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby". On other hand, the building Technologies Program of the US Department of Energy (DOE) has a similar aspiration, declaring that for 2020 the country must have “marketable zero energy homes” and “commercial zero energy buildings in 2025” (Sartori, Napolitano, Voss, 2012) Currently, implementing the nearly Zero Energy Building (nZEB) concept in Cuba is an indispensable way to improve the energy performance of buildings. Nevertheless, cultural and economic characteristics, tropical climate and social behavior are conditions demanding to adapt and redefine this concept for the Cuban context. Therefore, the discussions about the requirements needed to define an nZEB in Cuba, are ongoing. At the same time, this proves that it is necessary to train professionals better to face this new architecture paradigm.

The importance of designing and building differently to achieve the nZEB goal is recognized by Attia (Attia, 2012). One of the most recurrent requests is to carry out an integrated design approach in an interdisciplinary team working from the early design stage, in order to achieve the optimization of the building’s energy performance (Brunsgaard et al., 2014). This is difficult to be achieved in a professional practice, and even more for undergraduate students, because new knowledge about several engineering fields is needed, as well as the competence of integrating this knowledge.

The Cuban University has been recognized by the government as the main resource to carry out research works about regional problems. Influences of urban microclimate and low energy building design on energy consumption are issues discussed for years at the Architecture Faculty. A research group at the Architecture Faculty of the Technological University of Havana, José Antonio Echeverría (CUJAE) set during the last two academic courses a nearly Zero Energy Building design workshop. This action is also undertaken as part of the international VLIR USO TEAM project, "Renewable energy and bioclimatic architecture improving sustainability and development in Eco-touristic settlement: Las Terrazas". In the project the Architecture Faculty and Renewable Energy Technology Study Center (CETER, according to its initial letters in Spanish) of CUJAE, and the Architecture and Engineering Faculty of Ghent University (Belgium) are joining forces.

The present paper analyzes the main strategies and lessons learned from these experiences with transdisciplinary and integral program designed in order to optimize building’s energy use. The environmental and sustainable design teaching on the Havana Architecture Faculty in the past 40 years is also evaluated. Finally, the transformations made to the program of subjects in the last two courses, as well as some results for the work of the student carried out in different contexts are exposed.
National background

In the Architecture curriculum in Cuba, knowledge is structured into different disciplines incorporated in diverse subjects in two semesters along five years. Urban and Architectonic Design constitutes the main discipline that integrates the contents of seven other disciplines in seven exercises or design projects, taught in workshops. These workshops are guided by a professor although, currently, in the fifth year they are guided by a research group, in order to work related to more complex matters and multidisciplinary teams (Figure 1).

<table>
<thead>
<tr>
<th>Year</th>
<th>1st Semester</th>
<th>2nd Semester</th>
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<tbody>
<tr>
<td>1</td>
<td>Introduction to Architecture and Urbanism (IAU I)</td>
<td>Introduction to Architecture and Urbanism (IAU II)</td>
</tr>
<tr>
<td>3</td>
<td>Architectural and Urban Design (AUD III). NEW URBANIZATION</td>
<td>Architectural and Urban Design (AUD IV). MEDIUM COMPLEXITY BUILDING</td>
</tr>
<tr>
<td>4</td>
<td>Architectural and Urban Design (AUD V). URBAN REHABILITATION</td>
<td>Architectural and Urban Design (AUD VI). ARCHITECTURAL REHABILITATION</td>
</tr>
<tr>
<td>5</td>
<td>Architectural and Urban Design (AUD VII). DESIGN OF HIGH COMPLEXITY PROGRAMS</td>
<td>DIPLOMA THESIS</td>
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Figure 1. Design subject in the Architecture curriculum in Havana for years and semester. Source: Authors

To include the nearly zero energy building workshop as a part of Architecture curriculum is a new challenge to be reached. Even though this matter has not been tackled before, it’s a continuation of the teaching tradition following the goal to reach a be suitable architecture making a better use of natural resources.

Issues related to environmental design have been included in the study programme as specialized contents since the early sixties. New tools for environmental assessment were designed as part of the results of the faculty research works. The stick or shadow method to study the thrown shade in horizontal surfaces realized by professor Joaquin Rallo was one of these pioneer works (González Couret, 2004).

From the seventies, several studies were developed about thermal comfort in the Cuban context, thermal performance of building typologies and diverse urban morphologies, as well as performance of building materials and technologies (González Couret, 2004). These works were supported by measurements using measurement equipment from the former Soviet Union. These results were considered as basis for the Cuban standards about environment and energy in buildings design developed from the eighties, including natural ventilation and lighting, solar control, and thermal loads. Furthermore, the developed methodologies were also taken into account to improve teaching methods about environmental architectural and urban design. However, more quantitative methods based on calculation and numerical ranges were predominant during the 70’s and the 80’s (Alemany Barreras et al., 1986), which provoked certain negative reaction from the architecture students against mathematical approaches.

Even though major research results were not immediately applied in practice, their introduction into design solutions awarded in several competitions contributed to the demonstration of their validity. Some of such successful projects are The Habitat of Tomorrow in 1983 (project awarded in the international competition carried out by UNESCO), Bioclimatic Solar House in 1985 (National Award for Scientific Result), Three Designs to improve Leaving Conditions in the Mountainous Regions in 1989 (project awarded in a National Design International Conference for Sustainable Design of the Built Environment - SDBE London 2018 306
Competition), A sustainable Community Design in 1993 (project awarded in the international competition promoted by IUA in Chicago) and Bioclimatic and Progressive Social Housing in 1999 (Great Award in a National Design Competition) (González Couret, 2000). Likewise, these exercises have proved the benefit of using professor and student partnership method, to obtain in a limited period more holist and comprehensive solutions (González Couret and Portero Ricol, 2004).

The implementation of the fourth edition of architecture programs started in the nineties, addressing a wider character of the architects’ profile than the previous ones. However, a gradual change in content of environmental subjects became evident and the investigations in these fields were decreased. This change was due to numerous factors such as the deterioration of the measure equipment and the move of the specialists to the teaching activities. In addition, it was evidenced that the contents were not sufficiently apprehended in the students and neither were they applied in their entirety in the design exercises.

Two the reasons for not applying this knowledge in academic or real architecture projects, despite it was taught since the early sixties, has been the rejection of complex calculation methods and the generally existing dichotomy between design studio professors and specialised professors in scientific disciplines such as underestimate essential environmental requirements in design. While on one hand the design studio professors didn’t have this knowledge, on the other hand, the specialized professors used to consider these issues as the most important. Therefore, the assessments related to environmental design tended more to qualitative and perceptual analyses, and proved to be very complex to demonstrate scientifically.

Currently, knowledge and abilities of environmental design are acquired by the students mainly via a discipline ‘Environmental Design and Conditioning’), given during 5 semesters between the 2nd and 4th year of the curriculum. The integration between this knowledge and the main integrative discipline has been better than in previous periods. One of the reasons is that one half of the programmed hours is taught together with design workshop professor and it is evaluated in the same project exercise. This experience is developed not only between these two disciplines, but with most disciplines that intervene in each level from 3rd year of the Career.

The more frequent professional discussions about climatic change, environmental impact and sustainable development, have contributed to an increased recognition of environmental matters in teaching Architecture. For instance, the sustainability paradigm a has been included in the discipline Theory, Critique and History of Architecture and Urbanism, as well as in Technology and Structural Design, encouraging the use of local materials and technologies.

Integration of key processes of university studies (teaching, research and university extension) has been strengthened at CUJAE University, where students carry out their thesis and then, master and PhD investigation as a part of a research group, and achieved results are implemented in practice by the university extension, contributing to improve people quality of life.

Despite of the advances achieved in teaching and investigating these matters, at present there are still limitations to surpass. The knowledge and evaluations integration conceived from the curriculum conception depends on a highly collaborative and consensual work between the different professors involved in the designing exercise. Otherwise, the student may have the confusion of not knowing what point of view to assume in the face of different requests. In addition, in spite of the rescue of scientific analysis in the environmental design
discipline, very qualitative assessment persists and the teaching of related matters with equipment and technologies as air conditioning, artificial lighting and renewable sources of energy proves to be insufficient. Regardless of the international development in environmental simulation software, its use is very limited, mainly due to the high cost in the international market. The Faculty does not yet have measurement equipment to continue the investigations that had begun in previous decades.

The role of the University, of going in the vanguard as to the analyses of society problems, has caused the architectural paradigm that academic aspirations differ from those projected and executed in the professional context. In addition, some studies have to begin without enough starting information, or this information is not quite much managed, registered or processed. This entails besides that most of the paradigmatic examples of sustainability and energy efficiency, come from developed countries, that have different economic situations, weather and cultural traditions. This problem at has been discussed likewise in similar contexts (Benkari, 2013) for the importance of recognizing the socio-cultural sphere at the same level as the economic and environmental assessment are considered in sustainability discussions.

It is in this context that the nearly zero energy buildings design workshop is developed, it could contribute to solve problems that arise. To achieve this objective with the students, it could involve conceiving different complementary subjects that provide specific tools and knowledge, establish more interdisciplinary methods of teaching and design, simulate the architect's profession through team work and role plays, as well as define specific and integral solutions, aspects that are complex to achieve in the academic field.

**Teaching improvement. Working methods in nearly Zero Energy Building workshop**

Different subjects as part of the same project design was conceived to develop knowledge and skills more integrated into same Evaluation System

The design workshop was developed during the last academic year, due to the need to work with students better trained about specialized issues. Likewise, this was possible as a result of the enabled flexibility of the analytical program of the 5th year design subject to generate workshops related to ongoing investigations. The first experience developed during the academic course 2016-17 consisted of a workshop with 12 students working on nearly zero energy buildings used as touristic lodge in different central areas of Havana. During the second occasion (academic course 2017-18) the same amount of students were involved, but related to a wider subject, with the objective to improve sustainability in a rural community related to ecotourism (“Las Terrazas”, Cuba).

For both experiences, the program was structured from one design project for each semester, combined with four complementary subjects conceived in order to obtain a full integration. Although the design exercises are in different context, they present the same conceptual objective aimed at obtaining more training in the students. The design project of second semester constitutes furthermore the final diploma work, which the students have to present, discussing the theoretical framework and a detailed assessment from the initial stages. The other two complementary subjects consist of 54 optional hours and 32 elective hours related to technologies for renewable energy and environmental design in warm and humid climates, besides learning about the use of simulation software such as Energy Plus, for the architecctonic assessment, and ENVI-met, for urban analysis. Additionally, 124 hours for practical semi-professional activity are also conceived as part of the student’s comprehensive formation which is why they were inserted in some entities and project companies to evaluate
the energy consumption and to know the energy efficiency strategies that have been planned (Figure 2).

![Figure 2. Relationship between different subjects of 5th year. Source: authors](image)

Even though both courses had a similar programme, the experiences from the first year modified the initial program for the second one. The elective course about renewable energy was given during the 4th year, so that the students arrive in the 5th year with this knowledge. As well, an elective course about tools of participative design was offered during the second course, to be applied by the students when working with the community.

**Interdisciplinary discussions with professors from different specialties and community actors**

The subjects were directed by full professors and PhD students. The professors were architects and mechanical engineers, specialized in renewable energies. The workshop was conceived through seminars to evaluate the partial stages and ending of the project with the participation of stakeholders. This conception seeks to break traditional teaching approach, facing a problems based design in a multidisciplinary team. In the second step, the projects were also developed with the communal actors: population, leaders of the civil organizations, as well as executives of territorial institutions. Participative design techniques learned in the workshop were used for that (Figure 3).

![Figure 3. A feedback meeting with stakeholders and students to present initial ideas project design. Source: authors](image)

As part of the VLIRIOUS international project, the PhD students involved accomplished research stays at Ghent University, in order to update the available bibliography, to deepen the developed investigations, to learn simulation software and to use measurement equipment. This knowledge and abilities were quickly transmitted to undergraduate students by the given courses. Amount of student per professor (4:1) was lower than the traditional design studio in the Faculty (20:1), what allowed deeper discussion and analysis and more personalized attention.
The teaching and learning process in the design studio was developed in three stages: first to discuss essential theoretical concepts and to define the main requests of the projects; second, to design a general proposal, and third, to detail the main technical solutions and to analyze energy performance of buildings.

*Simulation of interdisciplinary professional practice in design workshop from role play and teamwork*

Team work was used as methodological resource during the first phase, where a specific task was assigned to each group for deepening and updating the collective knowledge. Among the assigned issues were: renewable energies, building equipment, passive and active design, touristic standards as well as urban assessment. The collective discussion of each aspect allowed to forge the main principles and leading concepts for the posterior design stages.

The designing proposal was carried on in an individual way in two last stages during the 2016-17 course, although the projects were discussed based on the role played by each student during the intermediate evaluation, in order to simulate the multidisciplinary team approach for the building design. In this sense, each student played a role according to the research task carried out during the first stage, even though they were not specialist in this issues, but they were the ones that developed more deeply into the study.

During the first design stage (2017-18 course), the students made proposals by groups, for the whole community or a particular component system while the last design step was developed individually. Groups were created combining students that analyzed different issues in the documentary first stage. During this experience, discussions with communal actors were essential. This entailed to transform the scope, because although at the beginning the goal was to delve mainly into energy issues, the discussion with the involved actors allowed to confirm that it was necessary to accomplish proposal related to key sectors in the community as landscape, dwellings, and public services.

*Results and learned experiences*

*Academic exercises. 2016-2017 course.*

In the exercises developed during the first year, the students worked up in three central zones of Havana: Old Havana, North Area of Havana Center and Vedado, which have a high touristic potential as well as diverse urban morphologies. The aim of the exercise was the design of a nearly zero energy building used for a cultural and city tourism market located on these central urban areas. Developed analysis and proposals allowed to define recommendations for this kind of projects.

Priority was given to natural ventilation complemented with roof-fans in all the spaces, although bedrooms were envisaged with air conditioning to fulfill the Cuban standards. The selected option was to design much more permeable buildings in such a way that they would not constitute a barrier to air flow inside the spaces. Among the used suitable design resources are fret-history, inner courtyards, in addition to include public services as snack-bar in the middle or last floor. These public services were generally designed including photovoltaic panels in order to allow ventilated roofs and in turn, propitiating the educational diffusion of this technology to the guests. The traditional spatial distribution was transformed in order to reach a better contact between indoors and outdoors in compact urban areas, by organizing bedrooms around a courtyard with an inner corridor.

Appropriate solutions for buildings in warm and humid weather were used, such as flexible windows and shadow protection, as well as hybrid system for power generation based
on renewable energy as solar thermal and photovoltaic systems. Small wind turbines were also incorporated in areas with high wind potential, even though this technology has not yet been used for buildings in the country (Figures 4-5).

Figures 4-5. A student’s design that use small wind turbine and photovoltaic roof as essential elements of the building conception. Source: students of last course 2017.

According to the Cuban standards, the architectural program for the touristic lodge was fitted with the aim to decrease energy consumption without affect regular performance. This type of building used to have minimum services additional to lodge, so restoration and recreational services are found on the surrounding urban context. It also included technical areas for renewable energy technologies and automation, not totally included in current standards.

The proposed architectural solutions reduced conventional energy consumption in between 30 and 40% respect to other similar buildings. One of the research results is the definition of the appropriate energy consumption range, as well as the identification of the main reasons for high energy consumption, based on 12 studied urban hotels. Nevertheless, energy balances and validation of these results by means of more precise simulations are pending tasks for later stages.

Even though proposed designs looked for a new esthetics trying to achieve that new technologies are not perceived as an addition, they also intended to be consistent with the patrimonial and contextual existing values. Design resources as the height of indoor spaces, design of windows and doors as well as shadow elements, were reinterpreted from the urban context, looking for endogenous solutions as the main energy saving strategy.

The need to develop studies beyond the building scale with the objective to evaluate potential and restrictions from the rest of the urban context to take advantage of renewable energies, became evident.

Figure 6-7. A student’s design that cover the terrace snack bar with a photovoltaic roof as well as it was simulated the envelope design performance. Source: students of last course 2017.
Academic exercises. 2017-2018 course.

The second academic experience was aiming to improve the energy performance and sustainability parameters for a community as a whole. The selected case-study was "Las Terrazas", a rural community located in a biosphere reserve, 60km from Havana, with high landscape values. This settlement was founded in the sixties, based on forest recovery as the main economic activity, and turned in the eighties to nature tourism.

The exposed results correspond to the work developed up to the first semester of the year, since the last diploma work step has not been concluded. Based on a diagnosis of problems and opportunities, a general development strategy include proposals as: to achieve a better use of the tourist resources through more accessible solutions and oriented route; to improve gastronomic and recreational services; to promote food production by permaculture techniques; to reuse and recycle solid wastes; to collect and use rainwater for domestic functions; the indoor spaces realignment to utilize new productive functions in the houses, and to improve housing living conditions. Community participation, as well as involved actors on each step has been one of the main achievements.

Figure 8-9. An eco-lodge design in Las Terrazas area. It was conceived the rain water use, photovoltaic system and composting toilet. Source: students of last course 2018.

Academic experience

Nearly Zero Energy Building is a new issue in Cuba, in such a way that discussions between students and professors allowed to touch this paradigm for the first time. Access to updated information as well as the generated discussion supported by the international project has contributed to consolidate and to deepen knowledge with regard to this matter.

While this was worked out with a small group of students (around 15 % of the total in this level), the energetic aspects were also included in others workshops for the majority of the architecture students. This fact became evident in the second course, when was started the work with students from 4th year of the career. It has put in practice the inclusion of students from inferior years to take part in the main group discussions, with the aim of achieving transmitting experiences and knowledge.

The evaluation with simulation software was still very preliminary, due to the fact that it was not possible for the researchers to develop the skills of using it. Based on the measurement equipment coming from VLIROUS project, it will be possible to validate simulation results by measurements in real cases in the near future.

Even though, it was conceived a design workshop with subjects that complement the formation with a total integration between them, the need to update own curricular subjects with the aim of achieving a better preparation of the students has become evident. In this
sense, it is advisable from the first years of the career to include all determining issues for a better building energy use, starting with fixed or very general elements, and gradually rising the level of complexity. This experience is part of the process of curriculum improvement, which is being developed at present to begin implementation in September 2019.

Transdisciplinary work between professors from the Study Center for Renewable Energy Technologies (CETER) and the Faculty of Architecture has been developed, despite the need to incorporate more specialists such as electric and automatic engineers as well as experts in air conditioning. In includes the convenience to develop multidisciplinary diploma works by students and professors of mechanical engineering and architecture and other specialties, despite the expected integration does not yet turn out well.

This is a complex process, because despite the recognition of its necessity, the structure and management system of the university is still organized by specialties, which make difficult to manage or schedules integrated academic activities and evaluations involving students from different faculties.

Working with two designing exercises with the same objective, let that students train in the subject matter and make their abilities perfect. The proposals in the second semesters were solutions that managed better to integrate technologies implicated in the buildings, including the RES, and the own design of the building with its surroundings.

![Figure 10-11. Transformation of Las Terrazas housing looking for better solar protections and incorporate renewable energy technology. Source: students of last course 2018.](image)

The communication between students and professors, together with the actors involved in the process, proved to be favorable. The proposals adapted to the concrete needs they had, but at the same time, they began to discuss problems not previously considered by the community, as water reuse, the use of renewable energies, and others.

This work also had made possible to improve the access to information, and involved actors are now more aware about importance of having more truthful data base to analyze their problems. Nevertheless, such experience is only possible if involved parts show a total interest about the process, as in “Las Terrazas” community. The university extension project developed with the community participation will enable to raise the environmental conscience of the population, and in turn, divulging knowledge that enables dialoguing more diaphanously to discuss proposals (Figure 12 and 13).
Figure 12-13. Socio-cultural work of university students with primary students. Identification of community values from drawings. Source: students of last course 2018.

Conclusions

In Cuba, the integration of sustainability in the teaching of Architectural design began more than 40 years ago, and from the very beginning it was characterized by the application of scientific results.

Energy efficiency and use of renewable energy constitutes a priority due to their impact on climatic change and the economic restrictions in Cuba. Some subjects from the architecture curriculum have been updated to this end, although even they still prove to be insufficient.

Design workshops with participation of professors from other fields and the integration of different disciplines involved in planning and designing processes now allow to improve the students' knowledge about sustainable buildings.

The experience showed the need to make integrated designs, in which the main energy saving strategy consists on the passive building design according to the features of its surrounding area. The use of renewable energy sources as well as considering the energy efficiency of equipment, must be a condition from the early stages of design, as one of the main guidelines for the building envelope. Decreasing energy consumption of buildings and using renewable energy sources imposes the design of a new architecture that at the same time, must respect heritage values of the local environment.

The validation of concepts and results by using measurement equipment and simulation software should be a part of the research processes and formation. To carry on international projects makes the acquisition of infrastructure possible, which is fundamental for southern countries.

The present work will continue in later stages that will enable to evaluate and correct the proposed solutions.

Acknowledgements

The authors gratefully acknowledge the support of Gent University and VLIR-UOS project (CU2017TEA435A103) in providing resources to develop researching and teaching. Many colleagues and students were involved in the development of course materials and resources, including teaching colleagues Walter Lopez from Piloto University of Bogota, Eline Himpe and Julio Vaillant Rebollar from Ghent University, undergraduate students of Architecture Faculty and professors of Mechanical Engineer Faculty from Havana; and Fernando Paredes from Las Terrazas.
References


Video creation as assessed coursework in sustainability subject areas.

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Abstract: Due to the holistic nature of sustainability and importance of raising understanding
across all types of actors in society, e.g. from public organisations to private companies to
communities to individuals, requires practitioners to communicate with multiple different
audiences and across multiple platforms to reach and engage all those who have an impact
on its uptake and implementation. In higher education preparing students for this wider,
multi-disciplinary landscape involves teaching how to effectively engage public as well as
disciplinary audiences. The creative communication skills needed to engage such audiences
can be illustrated to students through methods used to creatively engage students in their
studies. Improving student engagement is a common strategy to improve depth of learning
and technology can play a role in stimulating student interest in engaging with an academic
activity. The increasing public uptake and acceptance of video creation and uploading
indicates that this type of creative activity could enhance student engagement with assessed
coursework. To investigate this a series of trials utilising video creation as assessed
coursework is reported for a postgraduate course in carbon footprinting and undergraduate
courses in energy & buildings, across campuses in Dubai and Edinburgh. The trials provide
insight on the value of video creation in stimulating creativity, effects on student satisfaction,
issues for design & implementation and an assessment framework.

Keywords: engagement, coursework, assessment, education, video

1.0 Introduction

Enhancing technical and non-technical audience engagement in the interdisciplinary
concepts and solutions of sustainability requires advanced creative skills of interpretation and
audience alignment for effective communication. In teaching sustainability, these skills can
be introduced and practised through the use of non-traditional academic activities and tools.
In higher education teaching in general improving student engagement is a common strategy
in higher education to improve teaching and learning. Pursuing enhancement of teaching and
learning is an ongoing process that enables higher education to adapt to the ever-changing
societal environments of learners. It is a strategy that enables higher education to keep up
with changes in the contexts of students’ daily lives particularly with regard to changes in
technology, where evolution of students' understandings of new technologies alter their expectations and norms of communication and exposure to new knowledge.

One area where enhancing teaching and learning can have a positive impact is student engagement, where there is considered to be a causal relationship between engagement and academic achievement. Whilst student engagement can relate to a number of different teaching and learning issues, from engagement on programme structure and delivery to engagement with curriculum content, the underlying objective of improving student engagement is to, directly or indirectly, improve the effectiveness of teaching and student learning. In general terms, when we aim to improve such effectiveness we aim to stimulate student interest in their own learning generally and in course content or developing and practising particular intellectual skills specifically.

In addition to the potential enhanced teaching and learning has for improving student engagement, Ball et al (2012) suggest that ongoing shifts in the higher education market have led to having “up-to-date assessment activities” playing an important role in shaping a University’s reputation. It can be argued that such up-to-date activities include using communication tools or platforms that emerge in the public domain and that building learner competency in communicating through these is a core skill that affects employability and professional career readiness.

With living and working environments continually changing, the social acceptance or preference for particular methods of communications also changes. These changes are primarily driven by gradual acceptance of new or improved communication technologies. For example, consider the familiar case of the upward trend in uptake and then ubiquity of email or, more recently, social media platforms, both of which had technological and social acceptance drivers of their growth. The ever increasing uptake and acceptance of communication or information technologies in the daily lives of students has led to them arriving “…on college campuses ready to engage information in new ways” (Morris & Chawik, 2014). The evolution of uptake and influence on communication norms of such examples of recent technologies raises the question of whether the creation of online videos, increasingly facilitated by improvements to online access and video capture and editing, is another communication technology that has become significant in the daily lives of learners, both in higher education and elsewhere.

This study investigated the theoretical frame of video creation as an alternative assessment method and reports on trials of assessed video coursework across 65 students in three sustainability related courses at Heriot-Watt University.

2.0 Engagement in teaching and student learning

In the context of higher education, student engagement is commonly associated with engagement with curriculum where it can be considered to represent the “quality of effort students themselves devote to educationally purposeful activities that contribute directly to desired outcomes” (Beer et al, 2010). Engagement with educational activities, designed to address learning objectives, can be characterised by the extent of a student’s adoption of active and collaborative learning approaches as well as general participation and communication with peers and teachers (Beer et al, 2010). Whilst these characteristics, amongst others such as attendance, have been used as indicators of the level of a student’s engagement, engagement, to some degree, reflects a student’s level of satisfaction.

Munns and Woodward (2006) break student engagement down into two fundamental forms of “procedural”, reflecting students following procedures given to them by their tutors,
and “substantive”, reflecting “...a psychological investment” in the work or task being undertaken. These forms can arguably be aligned with surface and deep learning where procedural engagement is when students follow specific instructions that do not involve higher order cognitive processes resulting in surface learning and substantive engagement where higher order processes are required, such as critical evaluation or application of concepts to a problem. This differentiation between fundamental forms of engagement and the resultant implications for learning partly developed as a generalisation of the multidimensional construct described by Fredericks et al (2004) which frames engagement as having behavioural or operative, affective or emotional, and cognitive dimensions. This construct provides a useful frame to illustrate the engagement characteristics of surface and deep learning related to assessed coursework.

The behavioural or operative dimension of student engagement is characterised by behaviours such as effort, persistence, concentration, attention and contributing to group discussions in project work (Fredericks et al, 2004). The affective or emotional dimension can be characterised by level of interest, feelings, perceptions and attitudes (Archambault et al, 2009). Notably, Krapp et al (1992) report that interest in an activity can be transitory, being typically driven by novelty. As described by Fredericks et al (2004) the cognitive dimension is characterised by investment, or effort, in learning and self-regulation or strategic control of this effort. It is characterised by features such as extent of mental effort and the level and focus of motivation. In the context of assessed coursework it is possible to see how various aspects of this multidimensional construct of student engagement can be influenced, albeit not conclusively measurable, by procedural and substantive features of assessed coursework. For example, including peer assessment between individuals in group work can establish the importance of individuals contributing to group discussions thereby addressing the operative dimension. Similarly, it is possible that interest can be stimulated by use of novel activities or technologies and focussed motivation can be influenced by high marking ratings linked with a challenging task or scope of coursework.

As with all learning technologies it is difficult to attribute engagement benefits to any particular technology partly due to engagement being influenced by such a wide range of features of an academic activity. For example video creation as group work has effects generated by the video format itself, e.g. creative use of audio and visual devices, and by the group work element, e.g. active learning through group discussion. Due to this complexity this study of assessed video coursework trials focussed on impacts on student interest, motivation and creative expression which were considered to be unique effects of using a technology that is increasing rapidly in social acceptance and technological functionality. The main hypothesis that video coursework would stimulate greater interest and fuller engagement with coursework activities was based on the assumption that video creation not only helps deeper understanding but is also a current and increasingly familiar and accepted activity in the daily lives of students.

3.0 Video creation as assessed coursework or learning activity

Design of assessed coursework typically aims to address a number of factors which affect student learning and frame the type of knowledge, understanding and skills needed to pursue a professional career in a discipline. These range from the alignment of content and scope to intended learning outcomes, at a course level, and the relevance of types of coursework activities to future roles of graduates, at a programme level, to motivating student engagement with coursework activities, at a general level. In terms of skills valuable
in professional careers, confidence, clarity and audience engagement are common features of successful communication and there is growing interest by industry in graduates “…able to think and initiate creativity themselves” (Anon, 2014).

Creation of videos as a student learning activity has mostly been reported in the context of teacher training and medical and healthcare training programmes (e.g. Barry, 2012; Beacher et al, 2013 and Strand et al, 2013). In these contexts it has been used as a tool for self-reflection on physical procedure skills, e.g. suturing and patient interviewing, and communication, e.g. in-class teaching delivery. In these studies video creation was straightforward in terms of use of video equipment and editing software, effectively it simply involved setting up a video camera and recording specified activities that were to be assessed. Essentially video creation in these projects was a tool for remote assessment and as a learning resource for students such that the video part of these assessments was effectively extrinsic to the skills and practical knowledge being assessed as well as the communication of these.

Few other studies have investigated the affective and learning influence of video creation where the video itself is intrinsic to the work to be assessed, i.e. where the quality of communication, e.g. clarity and audience engagement, and the exploitation of the unique capabilities of video as an audio and visual communication medium accounted for a portion of the overall marks. However, some studies have touched on perceived benefits comparatively unique to video as a format. For example, study by Pereira et al (2014) of production of online videos in the assessment of nursing competencies found that video format does not necessarily result in students feeling less inhibited and that although video could encourage students to be creative this does not always happen. Greene & Crispi (2012) investigated student video creation in terms of the value marketing and accounting students felt they gained from the exercise. Similarly, Willmot et al (2012) investigated video reporting of group work in student projects with an aim to promote engagement and surveyed the participants on how they felt about the video element.

It is considered that rigorously evaluating the unique learning opportunities and benefits of video creation as an assessment activity requires identification, isolation and measurement of the particular features of student engagement that are affected by it independently from other general features of assessment such as its structure, e.g. group work, or extent of intellectual challenge. Although the assessed video coursework trials we conducted focussed on investigating stimulating student interest with a coursework activity and engagement with particular curriculum content it was possible to recognise more nuanced effects such as examples of creative thinking.

4.0 Video coursework trials

To investigate operational issues of using video creation as an assessment activity and evaluate the potential student engagement benefits, assessed coursework tasks were designed and implemented across a number of courses in Heriot-Watt University. The video coursework trials were initially planned to run in seven different courses under five separate degree programmes which had not previously utilised video coursework such that it was new to both students and faculty. Interestingly, the expected challenges of increased time and difficulty of using video recording and editing technology resulted in both students and faculty opting not to take this assessed coursework option in four of the courses hence the trials ran in a total of three courses. This is interesting as it illustrates the expectations students and faculty had of the implications of using a technology new to them in the context of teaching
and learning. Such prejudice is likely to be present for any new technology being introduced in teaching and learning.

Video creation can arguably provide unique opportunities to assess deep learning processes characterised for example by extent of creativity reflected by use of metaphors and audio-visual devices (e.g. volumes of coal to represent carbon emissions). However, aligning unique characteristics of creativity or creative thinking with intended learning outcomes of the trialled courses was beyond the scope of this project but should feature in future work in this area. This was partly due to the difficulty in clearly defining creativity in the context of curriculum content and clarity of scope in the intended learning outcomes of each course. However, some of the trials did define how quality would be assessed and attributed a significant proportion of marks to this element. This was considered to encourage students to evaluate the relevance, clarity and coherence of the results of their creativity, i.e. any metaphors or audio-visual devices they used.

<table>
<thead>
<tr>
<th>Coursework trial</th>
<th>Course</th>
<th>Aim</th>
<th>Role of group video element</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>MSc in Carbon Management - Carbon Footprinting (Edinburgh)</td>
<td>Explain the concept of carbon footprinting and how it is used to a non-specialist audience.</td>
<td>Intrinsic – student groups had to design a narrative using audio and visual devices that would correctly simplify and communicate a complex concept to a non-specialist audience. Video accounted for 10% of overall course mark.</td>
</tr>
<tr>
<td>B EDI</td>
<td>BEng in Architectural Engineering - Energy and Buildings (Edinburgh)</td>
<td>Design and propose a retrofit package of low carbon solutions for a rural Scottish estate to the building owner.</td>
<td>Intrinsic – student groups had to design a package of retrofit solutions and explain these in a way that would convince a building owner to choose their proposal over a competitors. Use of compelling narratives and/or audio visual devices to engage the viewer were defined as one of the core objectives of the videos to be created. Video accounted for 20% of overall course mark.</td>
</tr>
<tr>
<td>B DXB</td>
<td>BEng in Architectural Engineering - Energy and Buildings (Dubai)</td>
<td>Design and propose a retrofit package of low carbon solutions for a Dubai campus building to the building owner.</td>
<td>Intrinsic – students had to design a package of retrofit solutions and explain these in a way that would convince a building owner to choose their proposal over a competitors. Use of compelling narratives and/or audio visual devices to engage the viewer were defined as one of the core objectives of the videos to be created. Video accounted for 20% of overall course mark.</td>
</tr>
</tbody>
</table>
As noted above, to encourage creative thinking some trials defined quality characteristics of the video in terms of clarity, coherence, technical correctness and how engaging the video was in terms of metaphors used to explain core concepts and audio-visual features, see Table 2 below. It was considered giving these definitions would help students identify what they should be thinking about when designing their videos.

### Table 2 Example Assessment Scheme

<table>
<thead>
<tr>
<th>Area</th>
<th>Description</th>
<th>Marks available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation</td>
<td>Clarity, coherence and overall quality.</td>
<td>10</td>
</tr>
<tr>
<td>Communication</td>
<td>How engaging it is...</td>
<td>10</td>
</tr>
<tr>
<td>Technical</td>
<td>Correctness and depth of technical descriptions and evaluations.</td>
<td>10</td>
</tr>
<tr>
<td>Recommendations</td>
<td>Relevance and suitability of conclusions or proposed improvements.</td>
<td>10</td>
</tr>
</tbody>
</table>

Operationally it was necessary to provide access to digital video camcorders from which recordings could be downloaded to computers for editing and to provide online video editing software. Interestingly not all of the student groups made use of the video camcorders with most using their smartphones and own video camcorders. Similarly, all student groups opted to use video editing software available in the online public domain. These both indicate that the technologies, i.e. video camcorders and video editing software, are sufficiently developed and accepted by students for them to be confident in their use. However, whilst some students were extremely familiar with video creation, to the extent one student had their own “green screen” for integrating special effects, a relatively small number were not and spent a significant amount of time learning how to use both camcorders and video editing software. To allay potential concerns from students taking video coursework for the first time a guidance note was developed and included the following:

- Video length to be no more than 3 minutes and video file size to be no more than 300MB (an online Dropbox folder was provided for students groups to upload their video files)
- 10 step process of designing, producing and uploading a video
- Copyright legal requirements
- Access details for video editing software
- Links to online examples of similar types of videos from other universities

### 5.0 Findings of video coursework trials

A total of 65 students across two campuses and three separate courses took the video based coursework with each being asked to complete the pre- and post-coursework online questionnaires. Whilst the pre-coursework response rate was high the post-coursework response rate was too low to provide useful statistical analysis. In addition the students involved came from educational backgrounds with differing social attitudes to social media, i.e. students studying in the UK and the UAE. Due to this combination of small sample size and diversity of student contexts the findings can only be considered to identify types of
impacts of video coursework as opposed to indicating any hierarchy or relative strength of impacts.

5.1 Expectations and experiences

Results from the pre-coursework, i.e. before, online questionnaires show that the majority of students were either unsure (39%) or expected the video coursework to take longer than more usual coursework formats (39%). This lack of certainty, biased towards the negative, was further supported by the range of students’ expectations given in terms of what they expected to learn from video coursework. These ranged from the undecided, “No idea”, to the passively negative, “I expect that others can learn from our coursework”, to the misunderstanding of coursework focus, “How to prepare a professional video”.

Not all pre-coursework student expectations were negative or reflected misunderstanding. Additional student comments provided in the online questionnaires included “It is the first interesting coursework”; “I wish we had more coursework’s like this” and “I think this is a good idea, will like to try it out and give feedback if it should be used more. I’m not sure how much work it will be at the moment”. These comments indicate the concept of preparing a video did have a positive impact on interest for some students. However, there were a similar quantity of negative additional comments including, “I do not think I will learn more useful and course relevant things doing the video submission than any other type of assignment, probably even less...”. Overall the range of student expectations before starting the coursework can be understood when we consider this was the first time video creation had been applied within the programmes running the trials. These types of effects were considered during the design of the video coursework and resulted in limiting the proportion of each courses overall coursework mark allocated to the video coursework activity, i.e. 10% of overall course mark in one of the trials and 20% in the other two albeit in the case of the latter, student learning from the video coursework directly informed a final non-video coursework activity that accounted for an additional 20% of the overall course mark. On reflection, it could be that having low proportions of overall course marks allocated to the video submissions diluted the strength of student commitment and expectation of importance which would affect not only the extent of engagement in the coursework activity but also the online questionnaire response rate. Strategic learners could be expected to attribute less value to coursework activities that have a smaller impact on the overall marks for a course in comparison to other activities with greater marks potential.

The post-coursework comments were mainly, but not entirely, positive about the experience, e.g. “Whole video was enjoyable”; “Something different from another essay”; “Editing” and “Reviewing the video clips I had taken and then arranging them together for the coursework”.

In terms of stimulating student engagement it was found that student interest, as indicated by student comments, varied such that the video coursework trials showed no clear benefit in stimulating engagement. This is considered to have been affected by a number of factors including, it was a first video coursework for all students and staff and that there was a low marks weighting of video coursework in relation to other coursework activities having higher overall course mark weightings. However, in terms of stimulating creativity and the extent of psychological investment, reflected by the extent of creativity exercised by students, the video submissions across four courses showed a range of narrative approaches, audio-visual styles and active learning activities, e.g. students including interviews with external experts and non-academic friends. This indicates video coursework did stimulate students to
think creatively and broaden their approach to active learning type activities. It is considered this effect could be enhanced further by including peer-assessment and online public access to submitted videos on the basis of creating a more competitive context to the coursework activity.

Video creation, in comparison to structured written reports, arguably presents a more open scope for student creativity in communicating their ideas, knowledge and understanding. Such relatively greater opportunity to exercise creativity could impact on student engagement through being a driver of student interest and offering flexibility to support a wide range of creative preferences. Related to this, the approaches taken by students across the video coursework trials illustrates quite a wide range of creative expressions. These creative approaches differ fundamentally in terms of how they frame the narrative, scope and interpretation of content, the student groups felt was important to the coursework briefs they were working to. The main creative approaches taken by the participants included:

   i. Use of a physical model

   The design and construction of a physical model drove students to think about what the model would be used to express and in this way required a suitably deep understanding of the physical phenomena that were part of the problem being address in the coursework as well as the implications for suitability of solutions being evaluated.

   ![Use of a physical model](image1.png)

   **Figure 1 - Use of a physical model**

   ii. Hand-drawn animation

   The design and sequencing of hand-drawn animation drove students, within a group, to participate more openly with the rest of the group compared to if the drawings had been prepared away from the rest of the group. This activity can be considered to support group
cohesion in general and individual interaction in particular.

Figure 2 - Hand-drawn animation

### iii. Dramatisation

Design and scripting of a dramatized narrative motivated students to consider and explore how their curriculum specific knowledge and understanding could be abstracted to an engaging and enjoyable metaphor. This being created on video arguably supported student commitment to a creative process by providing the opportunity to design, script and review in an iterative process.

Figure 3 - Dramatisation

### iv. Annotated photographs

Designing graphic enhancement to real photographs provided students with the opportunity to experience a different type of visualisation of the implications of the solutions they were exploring and considering. Whilst this type of visual device could be readily produced in many other coursework formats, e.g. written reports and drawing portfolios, it has only been used by students in the video coursework trials indicating the video format
Some students drew inspiration from everyday use of audio-visual platforms in television news to adapt the same approach of interviewing experts in the topics they were exploring in their video coursework. The equivalent in other coursework formats would be referencing from literature however the face-to-face expert interviews of the video coursework trials goes a step further in that videos with these interviews also included referenced information from literature. This suggests the video format provided an additional stimulus to go beyond the standard approach of engaging relevant literature.

Staged group discussions provided students with the opportunity to showcase their individual knowledge and capture the dynamics of individuals in a group working together. This arguably drove students, in a group setting, to engage more deeply with each other through investing more time in understanding what points others were making. The opportunity, provided by video, to review, from the position as an equal observer, what each is saying can make it easier for individuals to more clearly see how their attitudes and
knowledge appears to others thereby offering the opportunity for deeper reflection.

Figure 6 - Group discussion

6.0 Conclusion

Video creation as an alternative form of assessed coursework can be considered to take advantage of the growing uptake and acceptance of video creation in the non-academic lives of students and thereby support adaptation of higher education courses to be relevant to societal developments. However, video as a medium of regular communication has yet to become a widely accepted communication norm such that the majority of students are familiar with its production. It was interesting to find that not all students in this study were as familiar with preparing videos as is indicated by statistics reported in the literature. This was indicated through trials of video based coursework, across four courses, where student expectations of producing videos were mostly negative or uncertain.

Although the trials of video coursework did not show clear benefits in terms of student engagement across all of the sample they did show a range of creative approaches expressed by students that have not emerged in other more conventional coursework formats. On the basis that creative thinking reflects deeper learning and that creativity was apparent in the video coursework trials, there is potential that further development of video coursework has potential to become a viable alternative presentation assessment activity.

Further work is needed to better understand the benefits of video coursework which should include comparison, across a larger sample, of accepted characteristics of student engagement, e.g. effort; active learning; persistence; interest; attitudes and cognitive effort, across video and more traditional coursework activities. There should also be more work on how to assess creativity and align this with targeted learning outcomes.

Overall the study has indicated that whilst video creation is not yet fully understood or accepted by all students and faculty, such that some are cautious and may have negative expectations, it is suitably novel and flexible to stimulate interest and provide opportunity for creative expression which can be harnessed to improve student engagement in terms of producing positive coursework experiences.

From our experiences of running these trials we suggest the following key tips for designing and operating an assessed activity involving student creation of videos:

- Define the audience for the produced videos, e.g. a client or a particular type of professional in the discipline related industry
- Set specific short time limits for video durations, i.e. 2 to 3 minutes.
- Give clear guidance of what students be addressing in the video and examples of similar student generated videos from other institutions.
- Setup an online repository of suitable storage capacity for video uploads.
- Provide guidance on copyright requirements.

Acknowledgement
The authors wish to thank the Centre for Teaching and Learning at Heriot Watt University who funded this study under their Enhancement Programme.

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Developing a framework for embedding Education for Sustainability (EfS) within the built environment sector in Egypt

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Abstract: Education for Sustainability (EfS) is a growing movement that seeks to prepare researchers, educators and practitioners for a career that embraces sustainable values and principles. Historically, this approach has been integrated to varying degrees across the globe, with developed countries typically applying this approach more widely than developing countries. Building Capacity for Sustainable Development of the Built Environment (BC-SDBE) project, has been set up to improve EfS within the Architecture and Engineering disciplines within Egypt. The aim of the project is to develop a viable framework for embedding sustainability principles, theories and applications into education and training. Achieving sustainable development in Egypt requires proactive engagement of stakeholders from educators, practitioners, developers, and policy makers. The first stage of the research undertaken in this project has gathered data surrounding the opinions on the current curricula through a stakeholder survey, themed workshops and open-ended questionnaires. In the second stage of the research, results from workshops held in Cairo surrounding the required skills for achieving holistic sustainability within the built environment sector are presented. This is followed by an open-ended questionnaire aimed at engaging academic groups involved in education in the built environment, which was undertaken during the second stakeholders’ workshop. The aim of this questionnaire is to reveal concepts and generate in-depth discussion surrounding curricula issues in Egypt and achieve consensus for the development of a proposed strategic framework which EfS at the heart of the education policy agenda in Egypt, progressively at all levels of education and professional training of graduates and practitioners in the built environment. This paper presents and discusses results from the second stage of the project methodology.

Keywords: Curricula Development, Educational Framework, Sustainable Built Environment, Questionnaire, Interviews, Workshops

Introduction and Context

Architecture discipline plays a key role in implementing sustainability within the built environment, as it has the benefit of blending creativity and scientific innovation, which impact upon all of society who interact with the built environment. If the discipline can truly develop and embed sustainability within the design, construction and use of the built environment, sustainability goals will be enhanced greatly (Taleghani, Ansari and Jennings, 2011). In terms of education, a broad knowledge set and ability to apply aspects from the three pillars of sustainability is essential at an early stage in the architects’ career. The major role of the education sector is to develop and build capacity for this action (UNESCO, 2003), as it has been shown that at Higher Education Level (HE), training and research activities have a considerable impact on implementing sustainability-related knowledge and innovations into practice (Bettencourt and Kaur, 2011; Frimana et al., 2018).

In the past, sustainability education has typically been ‘about’ sustainability, with content being delivered through courses in the form of transmissive surface learning (Altomonte et al., 2013). The current consensus around the topic suggests that it is essential that EfS is not just focused on the content of the curricula taught, but introduces the approach of integrating sustainability within the entire curricula design process (Altomonte et al., 2014). Despite the benefits of embedding sustainability within curricula, the process of curricula...
development often poses a number of challenges. The need for balance across curricula is also a key problem. In general, for Architecture and Engineering type courses; there are imbalances in curricula, most often with more technology-focussed courses or general theory found over sustainable design courses (Porras Álvarez et al., 2016).

The United Nations Decade for Education for Sustainable Development (DESD) that started initially in 2005-2014 gave an appropriate motivation to the educators to integrate sustainability into all aspects of education and training; through updated curricula, research and sustainability related activities (Thürer et al., 2018). However, the literature suggests that there has been a lack of integrated education and innovative teaching methods, which has led to educational failings and knowledge gaps surrounding sustainability (Tzonis, 2014). Education in both developed and developing countries needs to shift toward ‘Education for Sustainability’ or EfS, which encourages a greater understanding and ability to critically appraise and apply the sustainability concepts in a range of contexts (Tilbury, 2004; Iyer-Raniga and Andamon, 2016). Sustainable development (SD) is a key pillar for the socio-economic welfare of Egypt. The country is growing rapidly, and the demand for building in the civil and residential sectors has left a clear gap in terms of the skills available to deliver sustainable development in the built environment. The HE sector is encouraged to modernise to ensure that sustainability principles and theories are solidly embedded in their curricula, which in turn will reflect on more sustainable design in practice. Education for Sustainable Development (ESD) is a series of learning actions taken towards decision making on the long-term future of the three pillars of sustainability (Environment, Social and Economic). One of the core principles underpinning Education for Sustainable Development (ESD) is the development of “critical thinking skills, analytical skills, empathetic capacity and the ability to be an effective person who can take action to achieve desired development introducing education for sustainable development outcomes” (Tormey 2003, p. 2).

In Egypt specifically, education for sustainable development and environmental design is very limited and there is a considerable gap between the country’s current regulations, the market’s requirements and what ought to be taught in the departments of architecture (Dabaieh, Lashin and Elbably, 2017). In general, studies show that there is a significant difference between the architectural practice and education and integration of sustainability and environmental design requirements within them both (Farahat, 2011; Dessouky, 2016). These differences offer educators many challenges in putting the knowledge obtained at university into practice (Farahat, 2011; Dabaieh, Lashin and Elbably, 2017). Currently there is obvious desire to raise the sustainability knowledge and skills within architectural education at the HE levels (Dabaieh et al., 2018). Above all, it appears that sustainability in the built environment requires integration within the architectural education in Egypt. There is a belief that this can be delivered with new teaching systems that focus on the practical education rather than solely the theory only (Salama, 2015; Dessouky, 2016). Learners should be engaged in real life case studies to support and develop critical evaluation of available and innovative solutions, and reflection as learning approaches. Learners should also be encouraged to confidently disseminate their learning experience and knowledge in their profession through partnership with their peers in their communities and practices. They are introduced to new ways of working collaboratively with other stakeholders in the construction industry, including clients, contractors and suppliers (Elsharkawy and Zahiri,
Hence, the outcomes of sustainability-focused education and the training programmes are crucial to support the government strategic plans and goals in achieving the overall sustainability of the BE, on the macro and micro levels.

This paper presents and discusses research outcomes that will aid the development of an educational framework for embedding sustainability in the built environment in Egypt. Research has been carried out to assess and improve upon the educational and training levels in the country. The study presented includes a questionnaire-based survey with academics and presents results from stakeholder workshops involving academics, practitioners and students from the built environment sector.

Research methodology

The BC-SDBE project, as a capacity-building initiative, aims to provide learners with a concrete base of knowledge and understanding of the principles of sustainable development, both in theory and practice, focusing on critical and reflective application of theory and principles of sustainable development in practice. The education research side of the project aims to investigate the current state of sustainability education in Egypt in the built environment sector. To achieve this, a sequential mixed methods approach has been designed blending qualitative and quantitative research methods over the course of the project. This approach provided insight into the sustainability education aspect of the Architectural Engineering department at Ain Shams University, Cairo, which the project is using to serve as a microcosm for Egypt’s built environment education sector. The research methods are summarised below to set the context for the results discussed in this paper.

Skills gap online survey

A skills-gap survey was carried out for academic staff and students across a broad range of Higher Education Institutions (HEI’s) in Egypt. The aim of this survey was to develop an impression of the current built environment sector across Egypt and highlight the current skills gap in education, training and practice. The results from this survey have been recently discussed (Elsharkawy, 2017; and Elsharkawy and Zahiri, 2017).

Stakeholders’ workshops

Stakeholder workshops were carried out in Cairo during the project. These followed a moderated ‘round table’ discussion format. This allowed the results to be investigated for common themes and reveal areas for further research. The first Workshop (August 2017), discussed how the current system of education in the built environment area could be improved in Egypt. The discussions focused on three themes: ‘Curricula development’, ‘Continuing Professional Development’ and ‘Practice and Training’. The second workshop (March 2018) generated discussion surrounding the potential for interdisciplinary projects and the ways of embedding them within the current curricula to improve the employability of graduates in Egypt.

Stakeholders’ questionnaire

An open-ended questionnaire focusing on the recurring themes identified from the previous research work was distributed at the third stakeholder workshop in Cairo, held during March
The aim of the questionnaire was to elicit detailed responses surrounding the common themes identified in the workshops. The questionnaire was designed to generate further understanding related to the key skills requirements of students, the methods to develop these skills, the potential for curricula change, the perception of practical projects, and the perceived benefits and barriers of Academic – Industry collaboration for successful EfS. The answers to these responses were coded thematically for analysis by grouping responses according to the common themes presented in the responses.

Results and discussion

Skills gaps online survey

The survey results provided an insight into current education and practice of sustainable design in Egypt, with a sample of academics, practitioners, and students responding to a variety of questions. HEI’s involved included Ain Shams University, The British University in Egypt, Helwan University, Alexandria University and others. The results of this survey have been published in (Elsharkawy, 2017). However, the key result from this work shows that Education for sustainability needs improvement as only 20% of respondents acquired their sustainability knowledge at Undergraduate (UG) level. To build capacity for sustainable development in Egypt it is clear that a new strategic framework to embed sustainability at the start of a student’s career is necessary. Additional results show that there is often low participation in research due to limited resources both financial and physical, highlighting resource constraints as a barrier to overcome.

Stakeholder workshops

Following stakeholders’ workshops key recurring themes have been identified as key target areas to improve EfS at HEIs in Egypt. Students’ Skills were a key theme – these largely could be grouped into Technical skills that can be taught directly, such as research skills, lifecycle calculations, software use and choosing between electrical systems, building finishes etc. and soft skills which can be taught indirectly or developed by a student through the course of their study. These soft skills include aspects such as independent learning, creative thinking, teamwork and an appreciation for different disciplines agenda’s. A variety of teaching methods will need to be utilised to develop these broad range of skills. Teaching methods were discussed and received numerous suggestions during the workshops. Conventional teaching methods such as site visits, lectures and joint project work were suggested. However, more innovative techniques such as learning by teaching, problem based learning, capstone projects and peer based learning were mentioned. These suggestions show that there is an awareness of the need for varied teaching methods, and that implementing them will be the next step. Adopting innovative teaching methods is something on the HEI’s radar as these may develop interdisciplinary, technical and real world experience for students.

In addition, workshops have revealed key knowledge areas. These included standard areas of architectural education such as fundamentals of structure, fluid dynamics, heat transfer, lighting, acoustics, and building regulations. However, holistic approaches such as cultivating a specific mind-set were proposed. These included aspects such as appreciating independent learning, acquiring a wide range of sustainability-related knowledge, understanding building concepts not just calculations, and understanding buildings...
requirements. These mind-set topics go beyond course content alone, and suggest areas that HEIs can develop in future to produce well-rounded graduates. Additionally, workshop participants recognised that specific topics such as cost, waste management and site management need improving. The need for capacity-building was also discussed and can largely be improved by addressing 4 categories:

Training (CPD), skills improvement (critical thinking, team management and leadership), resource constraints (lack of research facilities and testing labs) and collaborative opportunities (new staff and industry networks, build interdisciplinary staff networks and encourage shared projects). Interdisciplinarity was also discussed and an overall action plan for embedding this within HEI’s was suggested and the suggestions fell into the following themes: Regulatory improvement (Agreeing university bylaws, developing collaboration with industry/practice (KTP’s, internships), curricula change (interdisciplinary projects, more peer interaction, graduation projects must follow real world scenarios) incentivising interdisciplinary integration (incentive/punishment plans) and evaluation (evaluate current resources, follow up plans and evaluate future outcomes).

Furthermore, employability was discussed as well. The workshops recognised that there are current strengths to build upon. Current strengths in terms of employability are the reputation of graduates (Highly aware, creative and technically literate) the position of architecture as a sector (rapidly modernising, large number of specialist tracks, ability to coordinate tools, ideas and technology) and current collaborative strengths (innovation hubs, professional studies and extracurricular provision). Employability weaknesses were identified as a lack of data (limited information on building codes, market needs, building economics and access to market data), resource issues (lack of them), need for innovation (real context often missing in teaching, largely one-way teaching methods, lack of new technologies, student factors (poor project management, not aware of other disciplines) and missing knowledge (lack of staff training and poor awareness of new materials and methods). Opportunities to embed employability were also highlighted as follow:

Curricula and student development (more collaboration with students, embed professional skills, teach new technologies, social media training) reputational opportunities (emphasise the quality of teaching staff, use Cairo location to advantage and large number of specialisation) collaborative opportunities (more internships, new markets and jobs). Threats to employability integration were identified as curricula related (need for international accreditation, need for technical training and high competition from the private education sector), regulatory threats (building codes are not mandatory, student numbers are controlled by government, economic (codes can be expensive to implement in terms of building technology or materials), collaborative barriers (the need for more coordination and communication between academic and industry) and external threats (population increase, rapid technological advances, new build cities not focusing on sustainability).

Finally, the suggested actions included improving collaboration (joint Academic-Industry supervision of student projects, Link research plans to market needs, Private-Public participation) developing more training (diversify curricula, applied interdisciplinary projects, develop staff training, project management and economy, maintenance systems, etc.) and encouraging attitude change (enhance the culture of interdisciplinarity).
Stakeholders’ questionnaire

Overall, eighteen respondents identified as academics responded to the survey. With a broad range of seniority levels represented (junior staff n = 9) (senior staff n = 9). Most respondents were from Ain Shams University, which is to be expected as they are the BC- SDBE project partner institution, but it is important to remember that this may bias the results and not be entirely representative of the HEI sector for the Built Environment in Egypt.

Concerning the first question, ‘What do you think the key skills an engineering or architect student needs to develop to successfully apply sustainability themes in their career?’; most respondents answered this question with many answers generated. Some 21 skills were suggested as being key for graduates to apply sustainability themes throughout their careers. The most commonly reported theme (9 respondents) was software and technology related skills. Other skills suggested included communication, teamwork skills, critical thinking and independent learning. These are all skills seen as desirable within the built environment literature (Iyer-Raniga and Andamon, 2016). Interestingly awareness of sustainability themes such as environmental issues, economics and social impacts were all referred to, but much less frequently. These issues are perhaps more important than the more easily identifiable skills. A broad awareness and understanding of sustainability issues is a key learning outcome that HEI’s must address (Murray and Cotgrave, 2007).

The second question, ‘Could you suggest any ways that these skills can be developed? What approaches do you use currently?’ received 13 responses. A wide range of responses were also submitted for Q2 – this question intended to provide more information surrounding current teaching methods, and whether any innovative solutions would be suggested. Critically looking at the methodology this question was posed poorly as respondent’s answers did not make clear what are current approaches, and what are suggestions. However, an analysis can be made. Workshops were the most commonly reported method, and are a conventional method of education. Interesting alternative ideas included: interdisciplinary themes ‘embedding requirements that influence students to interact with other disciplines’, assessing practical issues such as ‘simulating real life situations or big construction problems for students to solve’ and encouraging attitudinal change by developing ‘a sense of responsibility towards his/her society and environment at large’.

Figure 1. Q2 Word cloud (Source: Authors)
A range of methods were proposed as teaching tools to develop the skills mentioned in Q2. As shown in Fig. 1, the most common suggested methods are introducing more workshops, developing interdisciplinary work, and encouraging project work. However, innovative suggestions such as solving real world problems, promoting a sense of responsibility and involving industry in the academic process were also made. This is promising as education for sustainability requires a shift from conventional teacher lead education to a more student led model (Sewilam et al., 2015). There are many ways of teaching sustainability themes, ranging from traditional, technical and reflective methods (Christie et al., 2013) and a range should be incorporated into teaching to account for different learning styles (Elbarkouky, Aboshady and Salem, 2013), (Li et al., 2018).

As for the third question, ‘How easy is it to adjust the current curriculum, do you have the freedom to make changes and introduce new techniques?’ 15 respondents answered. However, the response was unanimous in that the current curricula taught at respondent institutions can be changed. This question uncovered additional themes. Some responses (n=3) agreed that there is a current willingness to change curricula to embed sustainability themes, 2 respondents suggest that curriculum is easy to change, 2 agree that minor changes can be made, and 2 respondents mentioned that university byelaws are being developed that will presumably enhance curricula change.

Curricula change will be a key method in adapting and integrating sustainability themes, and we can see from the literature that there is no standard solution to encouraging it (Ferrer-Balas et al., 2008) but it is widely accepted that the introduction of new course content, education delivery and assessment methods is essential. Curricula change should encourage a range of new Intended learning outcomes tailored to the required skills of Egypt’s built environment students. The most positive aspect revealed through the questionnaire is that there is real willingness to enact curricula change for sustainability, as willingness to change is often highlighted as a barrier (Bedawy, 2014). There will be barriers to overcome such as organisational, pedagogical and financial limitations (O’byrne, Dripps and Nicholas, 2014). These need to be investigated and understood to enact change within Egypt.

Thirteen respondents answered the fourth question, ‘Do you think that hands on practical projects are beneficial to students and why? Do these types of project happen often?’ The majority agreed that hands on projects are beneficial to students but do not occur often. One respondent reported that ‘The practice (of practical projects) enhances the perception of students about the profession and its challenges’ however these occur ‘not so often, more usually they are designed projects with conceptual requirements, that aren’t aligned with reality’. This quote suggests that practical based live projects such as working with real life case studies are beneficial for students – but they do not happen often. The implementation of practical projects can be challenging, a participant mentioned that ‘the students sometimes start participating in some practical projects through their workshops, but they do not get to the end’. Respondents broadly agree that practical projects do not occur enough. One respondent from a university outside of Egypt stated ‘Nowadays, yes these projects happen often, even in residential’ – which suggests that by making changes to the curricula, practical projects could become more popular. Dabaieh et al. (2018) present results from practical projects delivered through a ‘living lab’ for architectural students. They agree with our respondents that the approach ‘prepares students for the reality of architecture
practice in Egypt’ through practical application of theory. This practical learning also develops a student’s understanding of the whole design process showing how their actions made their design into a real building.

Finally, 14 responses were collected from the fifth and last question, ‘Do you think academics and practitioners could work together more to enhance student’s education? If so what do you think the main barriers are to working with industry?’ Respondents agreed that academics and practitioners could work more closely together to enhance student learning. However, a range of perceived barriers to working together with industry were raised by the academic respondents (Fig. 2). As seen in Fig 2. The most numerous response was that of student time pressure – suggesting that academic-industry collaboration is regarded as an extracurricular activity that students do not have time for. Other barriers included trust and cooperation, poor awareness of the potential benefits by both Academics and Industry, a lack of clear incentives, resource and cost barriers, and differences in working practices. Collaboration between Industry and academia could be an essential method for enhancing UG student’s education. Knowledge exchange, internships and demonstration projects provide an avenue for the practical application of skills and knowledge obtained through university courses. This academic – industry collaboration has long been an effective route to prepare students for the world of work (Samuel, Donovan and Lee, 2018). Through involvement with industry, students can develop ‘personal added value’ by demonstrating work experience, increased skill levels and enhanced employability (Brooks and Youngson, 2016) which provide long lasting effects on career progression.

The issue of time pressure for both students and industry appears is a key perceived barrier: One respondent stated ‘students do not have much time for extracurricular activities’ with another referring to ‘tight time slots’ for students. For industry, the issue of time is apparent with one respondent stating ‘professional architects are often busy, and have busy schedules and can hardly accommodate time for students work’ another respondent answered ‘consultancy offices are very busy and are not willing to receive students or send their (own) officers to be present and cooperate with academia’. Therefore, opportunities to engage with industry should be incorporated into the curricula, not left as an add-on. Other potential barriers such as trust, resources, cooperation, and expectations of Industry and Academics will only be resolved by developing mutual collaborations and raising awareness of collaborative benefit. One respondent summarised the issue: the barriers are ‘mainly the
lack of awareness on both sides for the importance of such exchanges, and the lack of awareness of the win-win situation that could be gained’.

**Conclusion – How to build a Strategic Framework**

The vision is that all HE built environment courses in Egypt contain a fully balanced, integrated and interdisciplinary approach to sustainability themes. These will produce graduates who are aware of the sustainability goals that they can contribute towards, and achieve them in a confident, efficient manner, which will benefit the environmental, social and economic prosperity of Egypt as it develops. From the literature and the results obtained through the BC-SDBE project to date, some key general suggestions for HEI’s in Egypt can be made. By incorporating these suggestions into future curricula developments, HEI’s can work towards developing a strategic framework to deliver the sustainability vision.

Any strategic framework for Egypt must take account of two sides, namely updating the pedagogy (curricula, skills, awareness and theory) to reflect upon new and innovative teaching styles which can be tailored to specific aims. The other key side for development is ensuring an increased real world application of the taught skills. This will most likely be achieved through problem based learning delivered through a variety of methods (such as hands on projects and industry collaboration) to encourage the application of theory. HEI’s in Egypt must ensure a balanced approach to future curricula change. It is crucial that both soft and hard skills are developed evenly and that course content does not become biased towards the ‘exciting’ topics of software and technology. These topics must be covered, but not at the expense of a broad understanding of sustainability principles. New updated curricula must increase the awareness of social, economic and environmental problems and equip students with the skills to solve them.

A key focus for curricula change, should be the adoption of innovative teaching methods such as problem based learning and compulsory credit bearing work focused on the resolution of real world problems. In addition to this, all modules should involve both interdisciplinary work and independent learning aspects to develop well rounded students. Perhaps more importantly still, new curricula should ensure that theory and practical projects are combined within modules to complement each other and enhance student learning. Academic – Industry partnerships should be fostered by HEI’s in Egypt. These are hugely beneficial for the development of a student’s confidence and allow the real-world application of the theory taught at university in a professional setting. In addition, these will develop a student’s employability – which will ensure sustainably aware graduates are employed where they can make a real-world impact.

Finally, there will be many barriers to updating and changing curricula such as Institutional, financial and regulatory issues, however there is a clear appetite for change, so HEI’s within Egypt should investigate the barriers at their own institutions, and seek a variety of methods to overcome these barriers to make curricula change for sustainability a reality. It is important to note that the questionnaire data is by no means exhaustive or fully representative of the HEI sector in Egypt due to low responses (n = 18). The results appear to match the literature in terms of its findings, but more extensive research will be required. Future work around EFS in Egypt should attempt to delve deeper into the factors affecting the choice of teaching methods and curricula development. The work could also investigate any
pre-existing relationships HEI’s have with industry at present, and determine methods to spread awareness of the benefits of academic-industry partnerships.

Acknowledgements

The British Council under the Newton Institutional Links project fund (Grant no. 2015EGY01) has funded this research project. The authors would also like to acknowledge the support of Ain Shams University and all the research team members involved in the SDBE project.

References


Assessing the Value of Environmental Analysis Tools in a Performance-Based Design Studio

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Abstract: It is well acknowledged that performance based analysis integrated early in the architectural design studio can yield better understanding of green building by means of continuous improvement to design alternatives. Integrating the analysis tools for advanced understanding of solar gain, daylight, wind flow, energy simulation at the early stages of design can provide students with quantified feedback between building geometry and measurable performance data. This helps in the evaluation of multiple design proposals and allows the students to make informed design decisions utilising a performance-based approach as a guiding tool. While students often excel in the application and analysis of these tools, a problem always emerge in the readiness of the students to apply the rest of their course work and specifically during the advanced level studios. An exploratory study in form of a questionnaire for a number of students was implemented following their tool learning to help indicate problematic areas in the learning process by identifying the limitations of the tools used, the application methodology and challenges associated with the data output interpretation and validation. A focus group exercise was later implemented where student projects were analysed, suggestions to a particular bundle of tools was documented and a development of the course content was proposed. The course outline was modified to suit the results of the questionnaire and the future outline development strategy is presented for further discussion and feedback.

Keywords: Course Development, Environmental Analysis Tools, Design studio, Performance-based, Simulation

Introduction

Teaching architectural design for a student half way in the program is considered a complex process in nature due to the enormous technological and pedagogical approaches as well the shift in paradigm of the professional market and the needed skill set for fresh graduates that evolves every day. Building performance simulation especially is utilized in the undergraduate and postgraduate programs during the different aspects of design of high performance buildings. Along with the architectural practice, integrating a sustainable green building approach into architectural education is becoming more of a necessity to train the future generations of professionals. Building performance simulation is a valuable approach to evaluate the design performance at an early stage and especially as students build advanced conceptual arguments where performance should be visualized than assumed.

In addition, the increased need to produce environmentally friendly design in the market is becoming more of a requirement than an option. As a result, the architectural design course outcomes are evolving where the students are required to present evidence of performance and eco-friendly thinking for their design proposals while achieving all other outcomes. Hence, enhancing their design problem solving skills creatively through project based-learning maintains the core of the architecture education, where learning is student oriented, experimental and case based.
Environmental analysis is one of the main elements to achieve the innovation in architectural education. Simulation tools are not only charts and data output tools, but are primary tools to advance the design thinking process. As stated by Hernan & Goldschmidt (1999), architectural education is about finding new approaches to help with the designers’ skills development in design problem-solving which is a critical requirement for future architects to be able to personalize and manipulate technology to keep up with professional needs and market demands. Accordingly, architecture schools are required to reform their curriculum according to current and emerging professional market demands, taking sustainable design approach into account. While using building performance tools in the studio is of great value to the learning process, some shortcomings and limitations are noted by Wilde (2017) and others to warn against the use of simulation tools without a key concept. His paper critically reviewed this issue and concluded with a suggestion that combines art, process and engineering, clarifying the attributes of each need to be quantified (classical physical measurement, building simulation, expert judgment, and user assessment) in the building performance simulation definition. An issue which is far complex than learning and applying a tool in the classroom.

Simulation courses are still based upon methods of knowledge transfer that lack innovative computer based training methods. Several studies explored innovation, visualisation, and suitability of tools in the design studio exploring issues relevant to its effectiveness and the growing demand for robust analysis that can be performed using everyday evolving technology against the everyday depreciating equipment. Wilde et al. (2002), recommended that introducing simulation at the right time and early in makes the assessment valuable since most environmental features are chosen predominantly without evaluation support, sometimes due to the challenges faced during simulation or the irrelevancy of the assessment with the design. A study by Pedrini et al (2005) recommended that during their evaluation using simulation tools to be exposed to introductory foundation classes on building physics and the technical foundations of building simulation so as to integrate the information in their design and be able to interpret the data output correctly. As stated by Cross (2006), designers are solution-led, not problem-led. “Idea generators” are built upon on computational simulations that have a profound ability not only to expand the limits of human imagination but also to point out the potential limitations of the human mind, thus expanding the creative process, Kostas (2006). Additional studies focused on the design studio explored the issue of integration and comfort in studio and reinforced the ongoing discussion actively targeted in architecture education, Delbin et al. (2006). For the solutions to be realized and evaluated, the visual aspect ought to be mastered, since the most regarded scope of simulation is the representative aspect, also mentioned by Asut (2008). A similar earlier study to the scope of this paper was based on interviews and surveys and aimed to understand the paradigms of Environmental Simulation in Performance Design and concluded with the significance of environmental simulation and its impact on the form shaping, program and fabric of the projects in design practice, Naboni (2013).

At the university level, architectural schools have set sustainable development of the built environment as a goal in the vision of the architectural education, Ceylan (2014). Of the earlier works published about the topic of educational approaches, a study assessed the suitability of one of the simulation tools as a design tool to be used by undergraduate students, Palme (2011). An experiment used three approaches to teaching building simulation, hands
on training, working on a simple model through an input/output screen and a game based approach. It was concluded that the game based approach, though the most unconventional, was the most favorable by all the students, Reinhart (2012) and a similar approach in, DeBaillie (2012) and Tarabieh et al., (2013). Rabenseifer (2015), addressed how the complexity of the simulation software and its required set of advanced skill can be an obstacle in the execution of the accurate simulation.

Earlier studies warned against running simulation during the very early stages alone as it will ignore major design decisions that would integrate the simulation with the design throughout the design process, Timothy (2013). Attia (2009) advised to open up the tools offered and not to limit as it may impact the design development and add more constraints. Other studies warned against the fundamental understanding of simulation data input/output, the quality, integrity and its interpretation such as Augenbroe (2011) who advised that for performative design that simulation assesses approximate not operational performance and accordingly care should be taken in the data interpretation. Two key studies by Biggs (1996) and Cottrell (2013) on working with simulation tools in studio demonstrated that students could not utilize the simulation tools fully and make it part of their design process as identified in previous studies as a result of a disconnect between the theoretical understanding and the application.

This is identified as a need for ‘threshold concept’ to understand the basic knowledge to enable the students to grasp the potential of simulation in design, Satish (2014). In response, Satish et. al. (2015) explored the curriculum re-structuring which included the integration of learning outcomes at all stages so that the students could relate the theory with practice. Earlier, Patrick et al. (2009) conducted a study to enhance the process through collaboration, it focused on the integration of building performance simulation within a higher education environment observing collaboration between architecture and engineering students in order to promote multidisciplinary environment and foster collaboration across different disciplines. Finally, Morrison et al. (2015), have also discussed the complexity of the simulation software and argued how through a continuous learning cycle with exposure to theories and application of the addressed tools from early education stages can effectively teach building performance simulation. Observations were made based upon courses delivery at a post graduate level; they addressed how that theory alone underpins the application of building simulation and the solution is experiential learning because its gives the user a deeper understanding of the deliver subject. Through this study a methodology have been established, learning by doing is driven by user participation.

A recent study was conducted in Australia, India, the US and the UK to investigate the teaching methods of building simulation in architecture programs to point out the possible educational barriers. The survey results concluded that architecture students would see the value building simulation it was part of their design studio education, but to have support when it comes to the interpretation of results, Hopfe et al. (2017). Similar studies by Özgür et al. (2015) and Al-Matarneh et al. (2017) investigated issues of ‘why’ rather than ‘how’ to use the tools. As a conclusion to these studies, the curriculum modified to reflect the assessment during the design phase and to integrate simulation tools at different stages to maximize the usefulness of environmental simulation in sustainable design and to bridge the gap the theory and practice.
In summary, the architectural world, practice and academia, along with the accreditation boards are demanding that the educational programs deliver the skill and ability to design with an environmental perspective. Environmental simulation tools are the best solution in both worlds of architectural practice and within architecture education, Clarke & Maver (1991) and Degelman & Soebarto (1996). Three key issues to be put into consideration: course content, students’ background, and teaching methodology. To assure effective learning cycle, design courses should introduce simple building models to teach building physics to novice users. As the students gain more experience with their simulation skills, the use of more complex models and tools can be added with the support of tutors and experts, Neto (2018).

Methodology
The main objective of the research is to analyze the role and value of environmental simulation tools in the architectural education and design process. Specifically, the study revolves around the use simulation tools in the design studio among the undergraduate early design courses, graduation design courses and graduates in practice. All the students were subjected to a learning by doing learning methodology and project based education where they were able to individually interact with the tool functionality using their own design projects at different levels of design development and experiment with the different capabilities of the available simulation tools. The students’ varied level and background in building physics and systems along with their general technical ability to work with the tools gave an insight to the educational and the professional architectural track when it comes to environmental simulation, also it was understood that not all of them were not be ready to conduct a full simulation exercise due to their knowledge and exposure to environmental simulation tools. A number of students (n=30) from almost all levels (Undergraduate and Graduate) who passed the main course introducing the tool concepts were selected for the present study. They participated in detailed questionnaire-based survey to measure the student acceptance of the simulation for design development and to get written student feedback to advance the development of the curriculum in the future. It’s also worth noting that all students surveyed are required to take one environmental controls course touching on issues of fundamentals and theory, and the following term they are required to take a core studio with a theme of sustainability in architectural design. Much of the tools learned took place during the second course.

Experiments and results
The survey is divided into three parts: A, B and C. Part A assesses the background of the student as relates to using simulation tools, the duration of exposure to the topic of simulation along with skills. The purpose of Part A is to understand the attitude towards the topic of simulation, delving into the learning methodology to measure the level of willingness to learn along with the tools used. This part ended with rating the satisfaction with the tool and if the assessment was valuable enough to be applied in the design. Also it was to map out the students’ skills and familiarity with environmental simulation, background knowledge and training. The results revealed the following: that 87% of the students were familiar with environmental simulation (Error! Reference source not found.) and had pervious training, 60% of the students exposed to environmental education from 0 to 12 months (Figure 2).
When asked to rate their simulation skills on a scale of 0, as to no skills, to 100, as proficient in simulation. The students reported an average of 55 (Figure 3). On the question of whether they have agree with the importance of simulation in design, the students were asked to rate their attitudes towards simulation 0 being Negative, 50 being Neutral and 100 being Positive. The reported average number was 60 among the students (Figure 4).

Investigating learning methodology, 40% reported that they received their education due to obligatory departmental courses, however 34% of the students reported that they have received the departmental courses but were willing to advance their learning using private tutoring and self-learning (Figure 5). Furthermore, when asked the tools utilized for simulation, the breakdown showed that Revit, 37 %, is the most commonly used simulation software followed by Vasari, 27 % (Figure 6).
When asked about the value of the assessment received, 56% of the students reported that they do not appreciate the information, because they did not know how to integrate it within their design (Figure 7). This information was rectified when asked if they would change their design after the assessment, 56% reported that they would not change it because it was too complex to apply and they did not have the *know-how* to input the results into their design (Figure 8).

![Figure 7. Appreciation of the tools](image1)

![Figure 8. Value of results](image2)

At the end of Part A of the survey, the students were asked to rate their satisfaction with the tool used, 0 being unsatisfied, 50 being neutral and 100 being satisfied, the reported average number was 46 (Figure 9). Part B, delved into the application of simulation along with other areas of application to observe their level of expertise and to know whether the students were able to relate the information given with other coursework or not. The results were as follows: carrying on from Part A, when asked if they tried using simulation tools in other coursework, 80% reported that they were required to use them again due to course obligations, but they used it again to gain experience and build on their knowledge (Figure 10).

![Figure 9. Satisfaction with the tool](image3)

![Figure 10. Application of knowledge gained](image4)

On the question of the most common areas of simulation application, 22% reported that they used it to represent sun pat, followed by 19% applying simulation to show shade and shadow, 14% for both energy simulation and weather information, 2% of the students reported that they used simulation during form generation phase (Figure 11). On the question of when did they receive their environmental simulation education during design, 47% reported that they learned about it during schematic phase (Figure 12).
Additionally, the students were asked if they have received their education at the right time, surprisingly, 73% of the students reported a “No”. When asked for an elaboration, they voiced that it should have been offered earlier, it could have helped with the form generation and early design considerations. In addition, simulation assessment was applied at later stages that there was no time to change it (Figure 13). On the other hand, when asked if the simulation helped with the answering the question why this form, 67% of the students reported yes if helped with the form validation (Figure 14).

The students were asked if the environmental simulation validated the design strategies or discouraged, 73% reported that their design was discouraged by the simulation assessment (Figure 15). When asked for further elaboration, 43% elaborated that they were discouraged because the assessment results were too advanced and they did not have the level of knowledge or expertise to comprehend it, while 32% voiced that the results were too complex to understand and apply into their design, while 21% stated that the simulation is conflicted with their design (Figure 16).
On the question of whether they were able to apply the results given on their design, 67% reported that they were not able to modify their design according to the assessment because it would have required a new design, the most common reason is that it was offered at a later stage (Figure 17). This showed that the problem is not with the information itself, it is about the application and the integration with the design. On the other hand, when asked if the problem was the data interpretation or application, 53% reported that it was data interpretation (Figure 18). This showed that the students faced a gap between the information offered and applying it on their design. The study of how to narrow the gap between the theory and practice and make simulation assessments relevant to the design projects of the students will be further researched in future studies.

Part C assesses the area of development and future considerations proposing virtual reality as one of the alternative for future simulation education. This part of the survey represented a focus group, where the students had the freedom to request and reform their experiences to help us shape the reformed curriculum and learning methodologies for future generations, we asked when the simulation should be introduced along with the preferred learning methodology. To assess how simulation is perceived, we asked about the value of environmental simulation as a design guiding tool. The results were as follows: 67% of the students reported that they have received their environmental simulation education in Year Two (Figure 19). When asked when environmental simulation should be offered, shockingly, 60% of the students voiced that it should be offered during earlier design studios (Figure 20).

When asked about the preferred method of environmental simulation delivery, 53% preferred hands-on training, while 47% preferred it as a game like structure (Figure 21). To explore the game structured education, the survey suggested virtual reality as an option for
education, 93% reported to agree with the option (Figure 22), furthermore, 73% voiced that they would consider using environmental simulation as a design guiding tool after the reformation of the teaching methods.

To conclude the survey with its three parts, the students were asked to add any points they think were missing from the survey, they requested that the environmental simulation education is very important and they are willing to learn it, but it needs to be offered in a less formal method, during early design stages and to be more fun. They recommended that simulation tools to be introduced early on in every design course to be able to relate the assessment results. Moreover, students would like to learn skills that will help them use complex software like Rhinoceros and 3Ds Max along with more practice with all simulation tools. Finally, they mentioned a widening gap between simulation teaching labs and the simulation application in real life or even in practice, in addition, they stressed on the issue of appreciation of the information given and the need to learn the ‘why’ of running a simulation exercise, rather than the ‘how’ to run simulation so that they can develop in depth design projects with validated ideas. To assist with the challenge of data interpretation, a suggestion of repeated assignments, in class and at home along with labs and presentations, the students would be able to practice how to interpret the data.

Course Development

Taking the previous survey into consideration as well as the continuous loop of student feedback, a mapping of the different stages of course transformation and the used tools in studio is presented below to show the stage development and tools used to facilitate knowledge learning and skills in the studio.

For the same course in a span of six years, the number of tools changes in studio varied as a result of the significant change in the specifications, technology, speed, applications and policy of the software tools generally used. For example, the ability to conduct energy simulation with ease became much easier with the recent upgrades in REVIT unlike the need for learning of complex packages such as Design Builder in the past were it is more geared towards the graduate and professional level students (Table 1).

The table below shows fourteen course offerings in a range of six years. It shows a challenge of learning different tools in the earlier parts of the course versus the later part of the course where one tool such as REVIT integrated a number of much needed analysis in one interface. One of the key challenges is the ability of the tool to handle different design
considerations and simulate it such as underground buildings or special shapes and specific conditions of smart screens, etc.

Table 1: Breakdown of the different tools by course offering (fall 2012 – spring 2018)

<table>
<thead>
<tr>
<th></th>
<th>Fall 2012</th>
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<th>Summer 2013</th>
<th>Fall 2013</th>
<th>Spring 2014</th>
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The table above shows a shift to more of tool integrated analysis in lieu of relying on a combination of tools with different outputs and learning techniques. In addition, a key factor of the success of the later used tools is the issue of “cloud” simulation which is an added benefit that guarantees robust analysis and the ability to retrieve the results anytime.

Discussion

Architectural programs continue to look for opportunities to integrate technology in the curriculum and to utilize simulation as one of the approaches to bridge issues of design development at different stages of the undergraduate education. To encourage students to be more involved and receptive to the topic of environmental simulation in their design development, the ideal tool should be easy to comprehend, user friendly, easy to handle geometric data, does not require detailed input data or expert knowledge in physics, able to run comparative analysis for the “what if” scenarios and can enable modifications on the building model and results in real-time as well as advise and recommendation tool to provide the needed help in real-time. Much of the current programs utilize simulation tools at different levels despite the limitations, challenges, learning speed and ability of application in a robust and expedited way. An actual course was used for the case study investigation and a sample of 30 students responded to a preliminary questionnaire. While the survey did not include the full number of the students involved in the program, it represents 10% of the total population which was satisfactory to the research team. Understanding that bias may have taken place, the research team will investigate possible methods to capture a larger population in the future and to combine it with statistical analysis to properly infer and generalize the outcomes of the study.

This study was to answer the question of is how environmental simulation tools should be integrated in undergraduate education. Along with the review of the literature in the field casts light on what constitutes the contribution to the future studies on this topic. The students tend to believe that their work is finished when they start to simulate their design, assessment results interpretation and reintegration of the optimized design along with a
repeated cycle of simulation must be realized and emphasized. There is misconception identified in the study on the difference between “running a successful simulation” and “interpretation of output”. There is a great benefit of real time design optimization and the ability to run multiple scenarios with environmental simulation tools which allows for a better learning experience and reinforce a studio design culture that is performative, iterative and addresses multiple dimensions. Even though having assessment results that are of quality, being able to comprehend and rerun the design, process and compare between different scenarios is essential. The goal of the modified architectural curricula should be to teach a user of environmental simulation tools and strategies rather than training a producer of simulation graphics. This notion addresses the request to know the ‘why’ rather than the ‘how’. The purpose of this study is to serve as a guiding method for updating the technical part of a course curriculum adapting to changes in technology and software needs. The ability to carry on a performance based studio is a growing need and as a result the studio culture and technology has to allow the students for real time scenario testing and experimentation in the shortest time possible. Accordingly, and due to the emerging need for quantified design results, the need to teach basic to advanced building physics may be required as well as systems design at an earlier stage in the program.

References


International Conference for Sustainable Design of the Built Environment - SDBE London 2018

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Chapter Three: Energy efficiency in buildings, Environmental design strategies in practice & Low and zero carbon design strategies
The energy savings assessment of an Integrated Shading System for Typical Office Spaces in Southern Europe

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Abstract: The issue of energy retrofitting of existing aged building stock for the improvement of indoor environmental conditions forms fields of high interest and extensive research. The present research aims to evaluate the integration of an adaptive louver shading system for the improvement of the indoor thermal comfort as well as of the energy efficiency of the building envelope of existing office buildings in Southern Europe. The system was evaluated by means of thermal analysis simulation using IES-VE 2017 software. In terms of thermal performance, cooling (CDH) and heating (HDH) degree-hours were selected as a quantitative indicator for the thermal performance evaluation of each geometrical configuration. The thermal performance analysis indicates that appropriate geometrical configurations of the louver shading system ensure suitable solar shading and adequate insolation during the cooling and heating period respectively and thus drastically reduce the annual degree-hour values compared to those of the reference scenario. Moreover, it indicates a notable reduction of the cooling and heating loads of the space under study, which leads to the decrease of its annual energy consumption. The research study confirms the positive contribution of the system under study as a solar shading and heat gains regulation system. The parallel investigation of thermal performance and energy consumption aspects offers a holistic and comprehensive approach to the investigation of the comfort conditions of the indoor built environment, while, at the same time, it establishes the concept of prosthetic renovation as a renewable energy strategy for the improvement of energy efficiency and indoor comfort of existing buildings.

Keywords: existing building stock, integrated shading system, thermal performance, energy consumption, thermal comfort

Introduction

The majority of aged building stock in European cities, mainly built during the postwar reconstruction decade, did not abide by any environmental principles or energy efficiency measurements. Due to the fact that no energy performance criteria or sustainable building policies had been provided, these buildings demonstrate high energy consumption to meet the heating and cooling demands. Most old buildings have poor or no insulation in walls and roofs, creating an envelope with high U-Value, which leads to heat loss through building structural components (Soutullo et al., 2016). Moreover, the extensive use of glazed surfaces in existing office building envelopes lets undesirable solar radiation go in through single glazed windows creating overheating of the indoor spaces and glare issues (Lopez et al, 2014). Furthermore, extensive glazing contributes to increased energy consumption for cooling and heating (Michael et al., 2016).

On the other hand, glazing allows a better visual connection between the indoor and outdoor environment as well as increased natural lighting, reducing the need for energy consumption for artificial lighting (Poirazis et al., 2007). It is noted that, according to the International Energy Agency (IEA), the operation of buildings consumes 40% of the world’s energy demands (International Energy Agency, 2009). In Europe, the energy consumption of buildings reaches 41% of the total energy consumption, with office buildings being one of the most intensive energy consumers (Janssen, 2004). As a result, new European Directives recommend strategies that will contribute to the improvement of the thermal performance
of these buildings, transforming them into nearly zero energy buildings by 2020 (Stazi et al., 2013; Directive 2010/31/EU). Therefore, the refurbishment of the existing office building stock is an approach that can tackle energy overconsumption and its negative impact on global climate changes (Callegari et al., 2015).

Currently, the environmental upgrade of the existing aged building stock for the improvement of indoor environmental conditions forms a field of high interest and extensive research (Valdiserri et al., 2016). The renovation of the existing building stock is preferred against demolition and reconstruction due to its limited ecological impact. Moreover, prosthetic renovation ensures the environmental upgrade of the buildings without the need for relocation of the occupants during the construction period (Almussaedd et al., 2014). The renovation of the façade could be an effective intervention, since it functions as a filter for external climatic parameters, e.g. solar radiation, daylight, wind, etc., providing the desired level of regulation of the environmental conditions (Selkowitz et al., 2004). In this framework, the design of the façade, the construction techniques and material selection have a significant influence on the indoor comfort of occupants as well as on the energy consumption of the building (Hammad et al., 2010).

Within this context, the current research addresses the issue of the environmental renovation of the existing building stock. More specifically, an environmental prosthetic renovation approach is proposed, consisting of an additional thermal insulation, replacement of the existing glazing and an integrated movable louver system. The integration of an adaptive shading louver system in appropriate geometrical configurations improves the energy efficiency of the building envelope, providing at the same time, better thermal conditions for the indoor environment. More specifically, the proposed system ensures suitable solar shading during the cooling period and thus, drastically reduces the energy consumption of the HVAC system and the annual cooling degree-hour values. Moreover, the system allows adequate insolation during the heating periods and thus maintains the heating loads at low levels or increases them slightly compared to the reference scenario.

**Literature Review**

As aforementioned this research deals with the environmental renovation of existing building stock, focusing on façades. An adaptive shading louver system is proposed since as mentioned previously, in the appropriate geometrical configurations, it has the prospect of improving the energy efficiency of the building envelope, provides better indoor thermal conditions while ensuring suitable solar shading and adequate insolation during the cooling and heating periods. The appropriate shading is necessary for office spaces in order to divert direct sunlight from entering the room, so as to avoid undesirable overheating and prevent thermal discomfort (Tzempelikos, 2008; Tzempelikos et al., 2007; Datta, 2001; Freewan et al., 2009). Many researches focus on more advanced integrated solutions which optimize the energy consumption of building envelopes, adapt to the external environmental conditions and address the owner’s desire to achieve high levels of occupant comfort (Michael et al., 2012). Hence these solutions must be cost-effective and operate over long periods with minimal maintenance in order to be selected and purchased by building owners (Hammad et al., 2010; Radhi et al., 2009).

The current research however, focuses on more conventional shading systems that can be integrated in the envelope of a building, internally or externally. Internal shadings were investigated in several studies, demonstrating their positive contribution to visual and
thermal performance improving glare issues and reducing cooling energy consumption (Singh et al., 2015, Atzeri et al., 2014). Atzeri et al. showed that external shading devices are more effective than internal systems, with the first contributing to a greater reduction of cooling loads in buildings located in hot climate regions with Mediterranean climate, i.e., Rome. Rotation angle, shape, size, configuration and colour of slats all have an impact on glare and visibility, but also on effective transmittance, absorption and reflectance of a window-blind system (Tzempelikos, 2008).

At the same time, louvers and blinds can be dynamic and adaptive depending on the occupants’ requirements for the environmental conditions of the built spaces. An extended literature investigating the performance of external adaptive façade systems in different latitudes is available (Hammad et al., 2010; Athienitis et al., 2002; Al Dakheel et al., 2017; Kim et al., 2009; Oh et al., 2012; Palmero-Marrero et al., 2009). The majority of these studies investigate the performance of external shading systems (Michael et al., 2016; Mofidi et al., 2017). Usually, these studies research external dynamic solar shading systems in comparison to fixed solar shading systems (Athienitis et al., 2002; Kim et al., 2009; Yao, 2014). Nielsen et al. researched different external solar shading systems and their impact on the total of energy demands, i.e. heating, cooling and artificial lighting, in a typical space in Denmark in different orientations. The study showed that the integration of suitable shading systems led to significant energy reduction (Nielsen et al., 2011). Moreover, Datta proved that external fixed horizontal louvers reduce the cooling loads in a building with south orientation in the summer but also result in the reduction of the overall annual primary energy loads of a building in Italy or other countries with Mediterranean climate.

Oh et al. optimized control strategies of slat-type blinds in buildings located in South Korea, through two stages. In the first stage, double-sided blinds were suggested by applying different reflectance between the front and back of the slat, and by fully rotating the slat when the system mode was switched between heating and cooling. When the double-sided blind was used, alongside controlled light dimmers, an energy saving of 24.6% could be achieved compared to the baseline case. In the second stage, the control strategies of slat angle and up/down control logic were developed to improve the energy efficiency. As a result, an energy saving of 29.2% could be achieved whilst glare was reduced to just 0.1%(Oh et al., 2012).

Conclusively, although the issue of environmental renovation of existing aged building stock for the improvement of indoor human comfort consists a research field of high interest, the existing literature on environmentally sustainable façade design remains rather limited. Moreover, the majority of relevant existing studies focus on either the building’s energy efficiency or on thermal performance of the indoor built environment (Bellia et al., 2013; Van Moeseke et al., 2007; Tzempelikos and Athienitis, 2007; Michael et al., 2011; Saelens et al., 2013). Therefore, literature dealing with both issues is quite limited (Kim et al., 2009; Palmero-Marrero et al., 2010).

Taking the above into account, the present research aims to evaluate the integration of a movable louver shading system for the parallel improvement of energy consumption and thermal comfort of existing office buildings through a series of integrated simulations. The focus is on investigating the performance of movable solar shading compared to no solar shading. The system is quantitatively evaluated, using software simulation analysis, aiming to provide better indoor thermal conditions.
Research Methodology

Case study description

Within this framework, a typical office space was selected for detailed investigation. For the selection of the most representative case study, an investigation of the typologies of the existing office building stock constructed in Europe during the last decades of the previous century was performed. This study indicated that the typical floor plan consists of a central linear corridor which gives access to office spaces on both sides. The typical office spaces are usually of rectangular shape and are placed in a vertical arrangement in relation to the corridor. This plan layout allows for openings along the external short side of the space. It is also noted that typical office spaces appear in all four orientations.

The office space under study has typical plan dimensions 3.50 x 5.50 x 2.75m (W x L x H), while the external façade accommodates a glazed opening with dimensions of 3.10 x 1.75m (W x H), located 1.00m above the finish floor level (Figure 1). The walls are made of clay bricks with plaster finish, while the exterior walls are thermally insulated with appropriate insulation materials. The upper concrete slab is covered by a false ceiling made of gypsum boards, while the lower concrete slab is covered by a typical suspended floor covered by timber tiles. The opening consists of aluminum window frames and double glazing.

Figure 1. (a) Plan layout and (b) section of a typical office space along with the integrated shading system at a horizontal configuration.

<table>
<thead>
<tr>
<th>Building components</th>
<th>Material (outside to inside)</th>
<th>Thickness (m)</th>
<th>Thermal conductivity (W/m K)</th>
<th>Thermal capacity (J/kg K)</th>
<th>Density (kg/m³)</th>
<th>U-Value (W/m²K)</th>
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<td>1.3</td>
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<td>2300</td>
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<td>Floor</td>
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<tr>
<td></td>
<td>glass</td>
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<td>1.06</td>
<td></td>
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<tr>
<td>Window</td>
<td>glass</td>
<td>0.006</td>
<td>1.06</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>air</td>
<td>0.012</td>
<td>-</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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The materials of the case under study, and thus, their thermal properties and U-Values, were selected according to the representative and typical materials and constructions methods used in typical office buildings in southern Europe during the last decades. The materials of the structural elements, along with their thermal characteristics, are presented in Table 1. Specifically, the U-Value of interior walls was set at 2.58 W/m²K, of exterior wall at 0.51 W/m²K, of floor and of ceiling at 2.00 W/m²K. The U-Value of glazing was set at 2.82 W/m²K. For the needs of the current study, the interior walls of the room, the floor and the roof are considered adiabatic.

**Integrated Adaptive Shading System**

The proposed movable shading system is located parallel to the façade of the building at a distance of 0.25m and integrated therein using lightweight metal frames. The movable louvers have a 0.25m width and are placed at a distance of 0.25m from each other. The louvers are made of aluminum with rather high reflectivity properties therefore allowing the reflection of sunlight. The louver slats of the system rotate in all possible angles from 0° to 180° and can be installed on horizontal or vertical axes. The flexibility of the system allows the appropriated configuration for optimum thermal performance depending on the façade’s orientation, the period of the year and hour of the day. Furthermore, the slat angles of the shading louver system varied between 15° and 165° rotating per 15° in each case as shown in Figure 2.

![Figure 2. Rotation angles under study on (a) the horizontal and (b) the vertical axes, with clockwise rotation per 15° in each case.](image)

**Simulation tool and building model**

IES-VE 2017, i.e. Integrated Environmental Solutions-Virtual Environment was selected for the evaluation of energy and thermal performance of typical office spaces in existing building stock. The tool several advantages as it offers default values and templates that facilitate quick entry and support a progression in thermal performance analysis giving quick answers in the early design stages, and even detailed analysis in later design phases. More importantly, IESVE was selected due to its accuracy, versatility and user-friendliness (Attia et al., 2009). Energy consumption will be the main objective of this study and will be used as the basis for comparisons.
The simulation of energy and thermal performance is performed for Larnaca, Cyprus (latitude 35°10' N and longitude 33°50' E). The weather in Cyprus is an intense Mediterranean climate, characterized by mild, rainy winters and hot, dry summers. The region of Larnaca is situated at the coastal area, i.e. climatic zone 01, according to the local classification of climatic zones of Cyprus that was carried out for the implementation of the energy performance of the buildings directive (2002/91/EC).

The office space is located on the third floor of the building. The interior walls of the room, the floor and the roof are considered adiabatic. This means that there is no heat transfer across the interior walls. Furthermore, for the office space simulations, it was considered that the room accommodates medium density occupancy, i.e. two adults with Maximum Sensible Gain 90W/Person, two computers of 350W and fluorescent luminaries with power density 10W/m² fixed on the ceiling. Moreover, the office room is heated and cooled by a HVAC system. During the winter, the heating set-point was set at 20°C, maintaining the room temperature at 20°C, while during the summer, the cooling set-point was set at 26°C, maintaining the room temperature at 26°C. These temperatures were considered to maintain operative temperatures within the range proposed by ISO 7730 (between 20°C and 26°C), and within thermal comfort requirements. The room infiltration was set to 0.8 Air Change per Hour (ACH).

The working hours were set from 08:00h to 18:00h on a daily basis except on weekends and holidays when the offices are closed. Consequently, occupancy was observed during working hours (08:00-18:00), and so was the relevant schedule. The schedule assumed for the use of HVAC and artificial lighting was from 08:00h to 18:00h daily, except weekends.

**Thermal comfort and energy consumption performance of the integrated shading system**

In order to evaluate the thermal performance of the integrated shading system under various geometrical configurations, two methodologies were followed. The first methodology focuses on the energy performance of the shading system, while the second one on the achievement of thermal comfort.

In this section, the energy performance of the proposed system was analysed, comparing its consumption to the reference scenario, i.e. without any shading system. More specifically, the energy consumption of the HVAC system, for each case of the proposed system, was calculated in Watt by adding external louvers at different angles. The slat angles of the shading louver system varied between 15° and 165° rotating by 15° in each case. Each configuration was examined during four representative days of the year. The energy consumption of the HVAC system was analysed, calculating the hourly loads needed for heating and cooling, which subsequently formed the basis on which these simulations were compared to the reference scenario regarding the effectiveness of the different configurations.

Thermal comfort is defined as the condition where satisfaction with the thermal environment is expressed and is assessed with subjective evaluation using the Adaptive Comfort Standard (ACS), which is incorporated in ASHRAE 55. This model provides 80% and 90% acceptability ranges, indicating the percentage of occupants expected to be comfortable at the indicated indoor and prevailing mean outdoor temperatures. This method is applicable in occupant-controlled naturally conditioned spaces, where occupants’ met rate ranges from 1.0 to 1.3 met and their clothing level ranges from 0.5 to 1.0 clo. The standard provides a graph of acceptable indoor temperature limits for 80% and 90%
acceptability, at prevailing mean outdoor temperatures. Provisions for higher operative temperatures are listed at air speeds above 0.3 m/s and up to 1.2 m/s (ASHRAE 55).

In the current research, all the proposed configurations of the louver shading system will be examined separately, as to whether their integration leads to the achievement of thermal comfort. Subsequently the cooling (CDH) and heating (HDH) degree-hours needed to achieve thermal comfort will be calculated in each case.

Results and Discussion

Energy consumption of the HVAC system was analyzed for all the rotation angles of the proposed louver system on the horizontal axis. For comparison purposes, the daily total of the HVAC loads was researched and analyzed below, while the daily total of the HVAC loads of the reference scenario is considered as a percentage of 100%. In Table 2, the simulation results of the total cooling loads are presented for June 21st and September 21st for south-facing spaces respectively, in order to comment on how the HVAC loads are affected by the integration of the proposed shading system.

As shown in Table 2, in south orientation the horizontal louver system with rotation angles of 30° and 45° does not affect the total HVAC consumption, maintaining it at 0 kWh during March 21st, like in the case of the reference scenario. Moreover, on December 21st both the reference scenario and the integration of the horizontal louver system with rotation angles of 30°, 45°, 60°, 75° and 90° does not affect the total HVAC consumption, maintaining it at 0 kWh. These results can be attributed to the ability of the proposed system to ensure adequate insolation during the heating period. Moreover, the mild climatic conditions during the winter, as well as the thermal insulation characteristics of the building envelope under study, contribute towards the aforementioned results. On June 21st, the rotation angles that result in the highest decrease of the total cooling loads are the cases of 75° and 90°, reaching a reduction of 1.15 kWh and a percentage of 9.4%, compared to the reference scenario that consumes 12.13 kWh. The other configurations present a smaller reduction fluctuating from 6.7% to 9.2%. On September 21st, the influence on the total daily cooling loads is more intense when integrating the horizontal shading system. More specifically, the integration of the system with a rotation angle of 75° causes the cooling loads to fall to 7.03 kWh reaching a significant reduction of 40.6% compared to the reference scenario that demands 17.31 kWh. All the other configurations under study note a smaller reduction ranging from 14.5% to 40.1%.

Regarding thermal performance, CDH and HDH were calculated for all the rotation angles of the proposed louver system on the horizontal axis. For comparison purposes, the daily total CDH and HDH was researched and analyzed below. More specifically, the simulation results are presented for the total cooling degree-hours for June 21st and September 21st for south-facing spaces, respectively, in order to comment on how the thermal performance is affected by the integration of the proposed shading system. In this stage, no comparison is made between March and December, owing to the fact that during both days all the configurations under study result in the minimization of the cooling degree-hours achieving thermal comfort.

As shown in Table 3, for South-oriented spaces and during June 21st, the rotation angles that result in the higher decrease of the cooling degree-hours are the cases of 90°, 105°, 120°, 135° and 150°, falling to 27.6 and 37.7 CDH for 80% and 90% acceptability limit respectively, compared to the reference scenario in which 38.2 and 48.2 CDH are demanded for 80% and 90% acceptability, respectively. Finally, on September 21st, the cooling degree-
hours for the reference scenario are significantly higher. More specifically, the cooling degree-hours are calculated at 87.0 and 97.0 for 80% and 90% acceptability, respectively, while the integration of the horizontal shading system with a rotation angle of 75° reduces the cooling degree-hours remarkably, falling to 31.9 and 41.9 CDH for 80% and 90% acceptability, respectively.

Table 2. Total daily HVAC loads for south-facing spaces for the horizontal louver shading system during March 21st, June 21st, September 21st and December 21st.

<table>
<thead>
<tr>
<th>Case</th>
<th>March 21st</th>
<th>June 21st</th>
<th>September 21st</th>
<th>December 21st</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vernal Equinox</td>
<td>Summer Solstice</td>
<td>Autumnal Equinox</td>
<td>Winter Solstice</td>
</tr>
<tr>
<td></td>
<td>heating loads</td>
<td>cooling loads</td>
<td>cooling loads</td>
<td>heating loads</td>
</tr>
<tr>
<td></td>
<td>kWh ±kWh</td>
<td>kWh ±kWh</td>
<td>% kWh ±kWh</td>
<td>% kWh ±kWh</td>
</tr>
<tr>
<td>1R.S.</td>
<td>0.00</td>
<td>12.13</td>
<td>100</td>
<td>17.31</td>
</tr>
<tr>
<td>15°</td>
<td>0.43 ±0.43</td>
<td>11.11</td>
<td>-1.02</td>
<td>91.6</td>
</tr>
<tr>
<td>30°</td>
<td>0.00</td>
<td>11.27</td>
<td>-0.86</td>
<td>92.9</td>
</tr>
<tr>
<td>45°</td>
<td>0.00</td>
<td>11.32</td>
<td>-0.81</td>
<td>93.3</td>
</tr>
<tr>
<td>60°</td>
<td>0.30 ±0.30</td>
<td>11.19</td>
<td>-0.94</td>
<td>92.2</td>
</tr>
<tr>
<td>75°</td>
<td>0.57 ±0.57</td>
<td>10.98</td>
<td>-1.15</td>
<td>90.6</td>
</tr>
<tr>
<td>90°</td>
<td>0.58 ±0.58</td>
<td>10.98</td>
<td>-1.15</td>
<td>90.6</td>
</tr>
<tr>
<td>105°</td>
<td>0.61 ±0.61</td>
<td>11.01</td>
<td>-1.12</td>
<td>90.8</td>
</tr>
<tr>
<td>120°</td>
<td>0.59 ±0.59</td>
<td>11.06</td>
<td>-1.07</td>
<td>91.2</td>
</tr>
<tr>
<td>135°</td>
<td>0.60 ±0.60</td>
<td>11.06</td>
<td>-1.07</td>
<td>91.2</td>
</tr>
<tr>
<td>150°</td>
<td>0.60 ±0.60</td>
<td>11.07</td>
<td>-1.06</td>
<td>91.2</td>
</tr>
<tr>
<td>165°</td>
<td>0.60 ±0.60</td>
<td>11.08</td>
<td>-1.05</td>
<td>91.4</td>
</tr>
</tbody>
</table>

1R.S.: reference scenario, i.e., without any shading system

Table 3. Cooling degree-hours (CDH) of the different configuration under study for south-facing spaces during March 21st, June 21st, September 21st and December 21st.

<table>
<thead>
<tr>
<th>Case</th>
<th>March 21st</th>
<th>June 21st</th>
<th>September 21st</th>
<th>December 21st</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vernal Equinox</td>
<td>Summer Solstice</td>
<td>Autumnal Equinox</td>
<td>Winter Solstice</td>
</tr>
<tr>
<td></td>
<td>CDH 80% 90%</td>
<td>CDH 80% 90%</td>
<td>CDH 80% 90%</td>
<td>CDH 80% 90%</td>
</tr>
<tr>
<td>1R.S.</td>
<td>0.0 0.2</td>
<td>38.2 48.2</td>
<td>87.0 97.0</td>
<td>0.0 0.5</td>
</tr>
<tr>
<td>15°</td>
<td>0.0 0.0</td>
<td>28.0 38.0</td>
<td>39.4 49.4</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>30°</td>
<td>0.0 0.0</td>
<td>29.2 39.2</td>
<td>64.9 74.9</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>45°</td>
<td>0.0 0.0</td>
<td>31.0 41.0</td>
<td>43.4 53.4</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>60°</td>
<td>0.0 0.0</td>
<td>29.1 39.1</td>
<td>32.5 42.5</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>75°</td>
<td>0.0 0.0</td>
<td>27.8 37.8</td>
<td>31.9 41.9</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>90°</td>
<td>0.0 0.0</td>
<td>27.6 37.6</td>
<td>32.3 42.3</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>105°</td>
<td>0.0 0.0</td>
<td>27.6 37.6</td>
<td>32.9 42.9</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>120°</td>
<td>0.0 0.0</td>
<td>27.6 37.6</td>
<td>33.6 43.6</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>135°</td>
<td>0.0 0.0</td>
<td>27.6 37.6</td>
<td>33.9 43.9</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>150°</td>
<td>0.0 0.0</td>
<td>27.6 37.6</td>
<td>34.0 44.0</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>165°</td>
<td>0.0 0.0</td>
<td>27.7 37.7</td>
<td>34.1 44.1</td>
<td>0.0 0.0</td>
</tr>
</tbody>
</table>

1R.S.: reference scenario, i.e., without any shading system
The obtained results demonstrate that the shading louver system could be a good case study for the different evaluated aspects, with significant benefits to energy saving and indoor comfort conditions. The integration of a movable dynamic louver system is important, while appropriate configurations that vary according to season can result in greater energy and thermal performance benefits.

The results are in line with studies showing that an external fixed horizontal louver system leads to a significant reduction in the cooling loads in a building with South orientation during summer (Datta, 2001; Saelens et al., 2013). The above simulation results are in line with research studies showing that appropriate shading systems on a south-facing façade could lead to about 50% decrease in the annual cooling energy demand. Although electric lighting demand is increased affected by shading patterns, an optimal balance between solar gains and internal gains is achieved and the total annual energy demand is also reduced by 12% (Tzempelikos et al., 2007; Atzeri et al., 2014) Also, the simulation results are in line with relevant research studies that confirm the reduction in the energy demand for heating and cooling through the integration of external dynamic façade systems that avoid undesirable overheating (Hammad et al., 2010; Tzempelikos et al., 2007; Al Dakheel et al., 2017; Oh et al., 2012; Nielsen et al., 2011). More specifically, this research showed that the horizontal fixed louvers with a light dimming sensor and an inclination angle of 75º for the south orientation had 9.4% and 40.6% energy savings for the cooling demand during the 21st of June and September, respectively. These results are in line with the relevant research of Hammad et al., which showed that the horizontal fixed louvers with a light dimming sensor and an inclination angle of −20º (that is 110º in the current research) for the south had 31.4% energy savings in hot climate areas, i.e., Abu Dhabi (Hammad et al., 2010). Furthermore, these specific research results indicate that horizontal louvers can decrease the energy consumption by 40.6% for cooling during the summer period. The above result is in line with the results of Kensek et al., who proved that horizontal louvers were able to rotate by 90º and decrease the energy consumption by 33% for cooling in humid subtropical climate; i.e., Dallas. However, in the present research, it is proved that there are configurations of horizontal louvers that maintain the heating loads minimized during the winter period, while in the study of Kensek et al. they can be decreased by 30% (Kensek et al., 2011).

Regarding thermal performance, this study is also in line with relevant research studies which indicate that indoor thermal comfort improves the thermal performance of the building envelope through the use of energy standards that can consequently provide a comfortable indoor environment. The use of overhang and louver devices can also improve the internal environment of buildings (Radhi et al., 2009). The above simulation results are also in line with research studies of indoor comfort levels demonstrating that appropriate variations in louver width, spacing, angles and materials influence greatly the internal comfort conditions of buildings located in southern Europe (Stazi et al., 2014). Furthermore, this paper is in line with other studies performed in different climatic conditions, proving that the dynamic operation of shading systems allows a significant improvement of energy efficiency and thus improved thermal comfort of occupants, compared to office spaces with no solar shading (Leong et al., 2017; Gago et al., 2015; Palmero-Marrero et al., 2010).

In conclusion, the reduction of the HVAC loads and cooling degree-hours of the space under study leads to the significant decrease in its annual energy consumption. Therefore, the parallel investigation of energy consumption and thermal performance aspects offers a
holistic and comprehensive approach to the investigation of the comfort conditions of the indoor built environment.

Conclusions

The study of energy consumption demonstrates that the variations of louver angles have significant incidence on summer and winter energy saving. Appropriate geometrical configurations of the horizontal proposed system allow suitable solar shading during the cooling period and thus, high percentages of reduced cooling loads compared to those of the reference scenario. Moreover, appropriate geometrical configurations ensure adequate insulation during the heating period and thus, maintain the heating loads at low levels. Finally, regarding indoor comfort levels, the study shows that the variations in louver angles greatly influence the internal comfort conditions. Therefore, the appropriate rotation angle of the louver system results in the significant reduction in heating and cooling degree-hours on each orientation.

Regarding energy performance, for south orientation the rotation angles of $30^\circ$ and $45^\circ$ on the horizontal axis perform the same as the reference scenario, presenting no demand for cooling or heating on March 21st. Regarding thermal comfort, all the configurations of the proposed horizontal shading system perform better than the reference scenario, presenting no CDH or HDH on March 21st. During the summer solstice, i.e. 21st June, the rotation angles of $75^\circ$ and $90^\circ$ are considered as the optimal cases due to low HVAC consumption. Regarding the energy consumption demanded for cooling, in order indoor thermal comfort to be achieved, the optimal rotation angles of the horizontal system are from $90^\circ$ to $150^\circ$. During the autumnal equinox, i.e. 21st September, the rotation angle of $75^\circ$ is considered as the optimal case in terms of both HVAC consumption and thermal comfort levels. Finally, during the winter solstice of December 21st, the rotation angles from $30^\circ$ to $90^\circ$ perform the same as the reference scenario, presenting no cooling or heating demand, while all the configurations of the proposed horizontal shading system demand no CDH or HDH to achieve thermal comfort.

Conclusively, a parallel comparative evaluation of energy performance along with thermal comfort assessment of the proposed shading system is presented below for south-facing spaces, focusing on the selection of the optimal cases based on the above simulation results. More specifically, during the vernal equinox, i.e., 21st March, the cases of $30^\circ$ and $45^\circ$ perform better in terms of HVAC system consumption, demanding no energy consumption for heating. Moreover, both of the rotation angles have no need for HDH or CDH to achieve thermal comfort. However, the rotation angle of $45^\circ$ can be selected as the optimal case, allowing better visual connection between the indoor and outdoor environment compared to the rotation angle of $30^\circ$. During the summer solstice, i.e. 21st June, the rotation angle of $90^\circ$ can be selected as the optimal case regarding HVAC consumption, demanding the lowest cooling loads. At the same time, there is no need for CDH to achieve thermal comfort. During the autumnal equinox, i.e. 21st September, regarding HVAC consumption and thermal comfort levels, the rotation angle of $75^\circ$ can be considered as the optimal case, demanding the lowest cooling loads and the lowest CDH in order for thermal comfort of 80% acceptability to be achieved. Finally, during the winter solstice, i.e. 21st December, the rotation angles of $30^\circ$, $45^\circ$, $60^\circ$, $75^\circ$ and $90^\circ$ present no loads of the HVAC system for heating and there appears no need for HDH or CDH to achieve thermal comfort. The integration of the proposed system at the rotation angle of $90^\circ$ is
selected as the optimal case as it allows better visual connection between the indoor and outdoor environment compared to the other rotation angles.

The above research findings indicate that the integration of the proposed louver shading system ensures suitable solar shading and adequate insolation of indoor spaces during the cooling and heating period respectively, which in effect, improves the thermal performance of the space under study. The decrease of energy consumption resulting from the use of a HVAC system and the reduction of the annual degree-hours, demonstrates its positive contribution to energy savings and indoor thermal comfort. It should be noted that following an analysis similar to the one presented herein, further research will allow for the investigation of the appropriate rotation axes and angles of the shading louver system, in spaces with other orientations. The adaptive characteristics of the system ensure the installation of the proposed system in a wide spectrum of locations across the world. Moreover, the research outcomes provide possibilities for a holistic environmental renovation method for existing office building stock, investigating the positive contribution of the integrated façade system in terms of shading and insolation, during the cooling and heating periods respectively. Finally, the research presented herein establishes the concept of prosthetic renovation as a renewable energy strategy for the improvement of indoor thermal comfort, along with the energy efficiency of the existing building stock.

References


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A comparative analysis of thermal performance of building envelope types over time

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\textsuperscript{2} Department of Landscape Design and Ecosystem Management, Faculty of Agriculture and Food Sciences, American University of Beirut.
\textsuperscript{3} Department of Architecture, Maroun Semaan Faculty of Engineering and Architecture, American University of Beirut.

Abstract: Different building envelope construction methods have a direct impact on indoor temperature and relative humidity variations with respect to prevailing outdoor climatic conditions. The purpose of this study is to explore how indoor temperature varies in buildings that were built at different times and therefore have varying wall construction types. Three residential buildings in Beirut were selected to represent construction methods of the 1920s, 1940s and 1970s. The buildings were chosen within the same street to ensure similar climatic and urban conditions. Climatic data loggers were installed inside and outside in the three locations to measure indoor and outdoor temperatures and relative humidity as well as outdoor solar radiation, wind direction and intensity. The collected data helped assess and evaluate the indoor environments with respect to the temperature variations. Results indicate a clear fluctuation of the hourly temperatures in the three spaces varying across the coldest and warmest days. In addition, the performance of the walls also differs on these days, thus having an impact on the internal temperature variations. The study shows that the performance of the sandstone wall is the most suitable because of the temperature differences between the external and internal surfaces of the wall and because of the resulting indoor temperatures. This research thus validates and contextualizes the role of building technologies in relation to indoor temperature variations. It creates a foundation for understanding the performance of different types of walls in existing buildings.

Keywords: external walls, construction methods, internal temperature, Mediterranean climate

Introduction

There is a need to focus on climate responsive design of buildings in the context of increased energy demands and the advent of climate change. The built environment consumes approximately 40\% of the energy and is responsible for approximately one third of greenhouse gas emissions (Ruparathna et al., 2016). In addition, comfort level demands are also predicted to grow as people spend more time indoors (Pérez-Lombard et al., 2008). With the advent of climate change, the demand for cooling and heating will increase depending on location in the world. It is now common practice to mechanically cool and/or heat indoor environments to provide occupants with thermally comfortable indoor settings (Mavrogianni et al., 2013). This process consumes high levels of energy which in turn result in increased emission of greenhouse gases (Papakostas et al., 2010). Different building envelope construction methods have a direct impact on indoor temperature and relative humidity variations with respect to prevailing outdoor climatic conditions (Mirrahimi et al., 2014, Muhy Al-Din et al., 2017). Therefore, one way to reduce energy consumption and emissions in buildings is to improve the performance of building envelopes (Mirrahimi et al., 2014, Muhy Al-Din et al., 2017, Toe et al., 2015).

The building stock in major cities already exists (Singh et al., 2016). For example, a study by the Council for Development and Reconstruction in Lebanon (CDR, 2010) shows that there
are around 17,000 buildings in Beirut city. Although there is no accurate count many of these buildings date from the past century. This suggests the need to understand the behavior of the building envelop in existing older buildings in order to improve their performance (Dili et al., 2011, Singh et al., 2016). Although the literature concerned with passive strategies for indoor thermal comfort highlights the importance of building materials and methods, the empirical measurements and the contribution of the wall composition to indoor thermal comfort are not sufficiently investigated (Singh et al., 2016). The purpose of this study is to explore how indoor temperature varies in buildings that were built at different times and therefore have varying wall construction types. It is proposed that by comparing indoor temperature variations in buildings of different time frames, one can therefore study the relationship between wall-construction techniques and indoor thermal comfort in existing buildings.

Methodology

Case Study Context

The city of Beirut offers a diverse inventory of residential buildings belonging to different periods (Saliba, 1998, Ragette, 1980). This potential for identifying various construction methods in the built environment of the city makes Beirut an adequate site to investigate passive strategies of residential buildings in Mediterranean contexts.

Selection of Buildings

Three spaces were selected in buildings that were built in 1926, 1948 and 1971- using different wall construction methods. The external walls were built with different components and have thicknesses of 25 cm sandstone, 14 cm poured concrete, and 20 cm concrete block construction respectively. As shown in Figure 1, the spaces are all located on Khalidi Street, in the Hamra district of Beirut. Figure 2 shows the adjacency of the three spaces whereby they are all located on the same side of the street, facing the North orientation, to control for solar incidence, prevailing winds as well as temperature and relative humidity because these climatic parameters affect indoor temperature and relative humidity variation (Toe et Al., 2015). The comparison is strengthened by the fact that the northern-facing external walls of the three spaces have similar window to wall ratios.

The buildings are named L1, L2 and L3, from east to west. The sitting room space in L1 (built in 1948) is located to the northwest of the building and is liked to a larger living room area and extends out to a terrace. The living room space in L2 (built in 1971) occupies the northeastern part of the apartment building and extends out to a balcony. The space in L3
(built in 1926) is within a house that has a Central Hall typology which is characteristic of houses built at that time in Beirut. This space has a wall exposed to the south orientation.

Figure 3 shows the following: the location of the spaces within the buildings, the location of the sensors, the configuration of the spaces in plan, section and the wall section with the associated construction materials.

**Data Collection Instruments and Methodology**

In each of the three spaces, two data loggers were placed, away from sources of heat, cold and moisture. The first, placed at about 2.5 meters from the building envelope and at a height of 1.6 meters from the floor measured indoor ambient temperature (°C) and relative humidity (%). The second, placed next to the internal face of the building wall, measured the walls internal and external surface temperature (°C) and also logged the ambient temperature at that location. Gathering data indoors was done using HOBO UX100-011 sensors, recording temperature and relative humidity, with a measurement range from -20 °C to +70 °C and an accuracy of ± 0.07 °C at 21 °C and a measurement range of 25% to 95% with accuracy ±5% for relative humidity.

The outdoor weather station ("WS" indication in Figure 2) was installed on the roof of an 11 floor building that is exposed in all orientations so that there are no obstructions to wind flow and solar radiation. This weather station measured the outdoor temperature (°C), the relative humidity (%), the wind speed (m/s), the wind direction (°) and the solar radiation (W/m²). A HOBO H21-USB Micro Station (a weatherproof data logger designed for applications requiring multi-channel monitoring of microclimates), an S-WDA –M003 Wind Direction Smart sensor and an S-WSB-M003 Wind Speed Smart Sensor (both designed to work with HOBO Stations) were set to record the data at one-hour interval starting from December 2017.

To account for variations in occupancy patterns, a chart was designed to document the number of users, lighting/plug loads, opening windows and operating AC units. One person in each household was asked to fill out the chart on a daily basis. Every two weeks, research assistants visited the households to collect the charts and download the information from the loggers.

**Data Analysis Method**

The data analyzed for this paper span from December 2017 to April 2018 but are part of data collected for a larger study intended to continue until December 2018. The data analysis in this first paper consists of a descriptive analysis using graphical displays of indoor variation trends in the three locations over the first five months. These graphs, showing the hourly temperature and relative humidity values for all the days of the month, allowed the comparison between monthly averages, coldest/warmest days and outdoor conditions. Using similar graphs, it was also possible to explore variations in internal and external surface temperatures of the external walls.

**Results**

Figure 4 shows the variations of indoor temperatures in the three spaces with respect to the variations of outdoor temperatures over the five months of the study. From Figure 4, it is apparent that the highest temperature occurred on the 23rd of March while the lowest was on the 26th of January. It is worthy to note that the space in L2 has, in general, throughout the months, the highest indoor temperatures whereas the space in L1 has the lowest.
The coolest day recorded a minimum outdoor temperature of 9.2°C with an average outdoor temperature for the day of 11.4°C. However, the warmest day recorded a maximum outdoor temperature of 33.5°C with an average outdoor temperature for the day of 28.2°C.

To better understand the performance of the different walls on the months with the coolest and warmest days, monthly graphs representing the variation of temperature and relative humidity over the 24 hours of the day for the three spaces were prepared (Figures 5 to 10). The colored lines (as indicated in the legend) show the variations of indoor temperature, the hourly average outdoor temperature, the hourly average relative humidity and the hourly average indoor temperature over one month. The main results for the three locations are summarized in Table 1 for January and Table 2 for March.

Table 1: Comparison of indoor temperatures by location in January 2018

<table>
<thead>
<tr>
<th></th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>average indoor vs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average outdoor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperatures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5pm to 8am:</td>
<td>2°C higher</td>
<td></td>
<td>5 pm to 9 am: varies from around 1°C to 2°C higher</td>
</tr>
<tr>
<td>8am to 5pm:</td>
<td>1°C lower</td>
<td></td>
<td>9 am to 5 pm: Gradual decrease to become almost 1°C lower</td>
</tr>
<tr>
<td>coldest indoor vs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coldest outdoor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperatures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throughout the day:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>higher, varies by 1°C (around midnight) to 3.5°C at 7pm.</td>
<td></td>
<td></td>
<td>Mostly higher by 3°C to 5°C</td>
</tr>
<tr>
<td>11 am to 1pm:</td>
<td>about 1°C lower</td>
<td></td>
<td>Around 12 pm: less than 1°C higher (minimum difference)</td>
</tr>
<tr>
<td>warmest indoor vs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>warmest outdoor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperatures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throughout the day:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower by 2°C to 5°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 pm till 8 pm:</td>
<td>1°C higher</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Comparison of indoor temperatures in March 2018

<table>
<thead>
<tr>
<th></th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>average indoor vs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average outdoor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperatures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 pm till 8 am:</td>
<td>consistently higher by about 2°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 am to 3 pm:</td>
<td>lower by about 1°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>warmest indoor vs.</td>
<td>lower by 2°C to 5°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>warmest outdoor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperatures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throughout the day:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower by 2°C to 10°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 pm till 8 pm:</td>
<td>1°C higher</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throughout the day:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower by 8°C to 15°C with peak at 12 pm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 7:00 pm:</td>
<td>lowest temperature difference (a fraction of a degree)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Figure 3: Plans, sections and wall sections of the three units

1. Reinforced concrete slab
2. Wooden frame and mullions single glazing
3. Poured concrete 14cm wall
4. Concrete Masonry Unit blocks 18cm
5. Aluminium frame single glazing
6. Marble column
7. Wooden frame single glazing
8. Sandstone masonry 22/23cm
Figure 4: Variation of the indoor daily average temperature in the three spaces and the daily outdoor average temperature over five months.

The following graphs illustrate the hourly indoor and outdoor variations in the three locations.

Figure 5: Variation of the hourly indoor and outdoor temperature over the month of January in Location1.
Figure 6: Variation of the hourly indoor and outdoor temperature over the month of January in Location 2

Figure 7: Variation of the hourly indoor and outdoor temperature over the month of January in Location 3

Figure 8: Variation of the hourly indoor and outdoor temperature over the month of March in Location 1
Figure 9: Variation of the hourly indoor and outdoor temperature over the month of March in Location 2

Figure 10: Variation of the hourly indoor and outdoor temperature over the month of March in Location 3

Wall surface temperature

The graphs below show the internal and external surface temperatures of the different walls in the three spaces. The graphs represent the indoor surface temperature, the outdoor surface temperature, the ambient temperature, the indoor temperature and the relative humidity (%) with respect to the outdoor temperature, the relative humidity, the wind speed and the solar radiations during the warmest and coolest days of the study period.

Figure 11 shows that in location 1, the wall’s outdoor surface temperature is generally lower than the indoor surface temperature by about 0.6°C. Between noon and 2 pm, the outdoor temperature increases to become slightly higher than the indoor surface temperature. In Location 2 (Figure 12) the outdoor surface temperature is consistently higher than the indoor surface temperature by a range of 1 to 3°C, during the coolest day. The difference is the lowest at 12 pm. In location 3 (Figure 13) during the coolest day, the outdoor surface temperature is consistently lower than the indoor surface temperature by a range of about 1.5°C to 2.5°C.
In location 1 (Figure 14) during the warmest day, the indoor surface temperature varies with the outdoor surface temperature which is higher by about 1.5°C between 6 am and 12:30 pm. In location 2 (Figure 15), during the warmest day, the indoor surface temperature is higher than the outdoor surface temperature by a range of 1 to 2.5°C from 5 am till midnight. Between midnight and 5 am the difference between outdoor and indoor
surface temperatures is minimal. In location 3 (Figure 16) during the warmest day, the indoor surface temperature is consistently lower than the outdoor surface temperature by a range of 1 to 5°C. The difference is the largest between 10 am and 12 pm.

Figure 14: Indoor temperatures and relative humidity in location 1 with respect to the outdoor conditions during the warmest day – March 23, 2018

Figure 15: Indoor temperatures and relative humidity in location 2 with respect to the outdoor conditions during the warmest day – March 23, 2018

Figure 16: Indoor temperatures and relative humidity in location 3 with respect to the outdoor conditions during the warmest day – March 23, 2018
**Occupancy patterns**

Location 1 is inhabited by a family of four members. It is usually occupied in the afternoon and evening. The space has one television, three lighting fixtures and one air conditioner. During the daytime, the windows are opened to ventilate the house. During the holidays, the space is used by a larger number of people. Location 2 is occupied by one person who uses the space during early morning, afternoon and evening. The space, opens to an entrance hall, has 3 lighting fixtures and one air conditioner. The resident, who travels more than once a month, leaves the house empty most of the time. Location 3 is occupied by a family of 6 members but it is not furnished and it is used only at lunchtime.

**Discussion/Conclusion**

There is a clear fluctuation of the hourly temperatures in the three spaces varying across the coldest and warmest days. In addition, the performance of the walls also differs on these days, thus having an impact on the internal temperature variations.

As expected, the external wall of the space in location 3 performs best on both the coolest and warmest days because the temperature difference between the external and internal surfaces is large (varying between 2 and 5°C). On the warmest day, the indoor temperature is relatively stable (16°C) despite the fluctuations of the outdoor temperature. It is consistently lower than the outdoor temperature reaching around a 10°C difference at approximately noon. This illustrates the positive performance (due to the thermal capacity of the wall). Whereas, the temperature, on this warmest day, was lowest in the space of location 3 it was highest in the space of location 2. The indoor temperatures in the spaces of locations 1 and 2 fluctuate between 17 and 22°C. In the walls of the spaces in locations 1 and 2, this temperature difference between the external and internal surfaces does not exceed 2°C. Moreover, the temperature in the space of location 3 is the same during the warmest day and the coolest day. This is associated with the thermal mass capacity of the sand stone and is consistent with the surface temperature variations mentioned above (Balaras, 1996, Juarez, 2014). Maintaining stable indoor temperatures (at around 16°C) on both the coldest and warmest days improves indoor comfort conditions.

The walls of the spaces in locations 1 and 2 do not perform as well as the wall discussed above. The internal and external temperature variations reach slightly higher than 2°C. Consequently, the indoor temperatures also fluctuate between 2°C and 4°C as shown in Figures 11, 12 14 and 15.

On the coldest day, the indoor surface temperature is slightly higher than the outdoor surface temperature of the wall of the space in location 1. This low temperature difference indicates that the wall’s performance is acceptable in helping to maintain the indoor temperature.

In conclusion, the study shows that the performance of the wall in the space of location 3 is the most suitable because of the temperature differences between the external and internal surfaces of the wall and because of the resulting indoor temperatures.

There are other reasons that could explain the differences in indoor temperatures. First, the occupancy pattern and the internal gain. The three spaces were used differently. The space in location 1 was mostly occupied by a family composed of 4 people. The space in location 2 was inhabited by a person who traveled most of the time while the space in location 3 was generally empty. Second, the window to wall ratio (and floor ratio) affects the temperature inside significantly affecting the heat exchange between the indoor and outdoor environments. Third, the ventilation that helps in decreasing the impact of internal gains on
the space. Location 1 is ventilated often in order to be cool. Finally, the orientation whereby the three spaces are oriented north thus, they are not affected by the direct solar radiation during the months addressed in this study but may be impacted by solar radiation during the summer months when the days are longer.

This study creates a foundation for understanding the performance of different types of walls in existing buildings. Further work would build on this information by studying the characteristics of local materials (sandstone, concrete mixes, plaster, glazing, etc.) and extending the data collection to span one whole year to allow a better assessment of the indoor temperature variations with respect to the wall construction type in all four seasons. Furthermore, associating indoor relative humidity levels with the indoor temperatures would allow a more thorough understanding of comfort as per context specific psychometric charts. In addition, other factors need to be controlled by applying statistical analysis using time series modelling and repeating the study in a situation where the occupancy patterns and behaviors are controlled.

References


**Bio-mimicry as a tool for minimizing energy consumption and improvement of thermal comfort: The case of office buildings.**

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**Abstract:** Throughout history, architects have dealt with nature as an optimal inspired model for building design forms, stylistic inspirations and possibly for recent approaches to decoration. A yelling for a different attitude of dealing with nature has almost begun; achieving the scientists’ view, to learn from nature rather than to control it. Translating biological adaptations into architectural solutions through bio-mimicking various levels of an organism’s behavior can be easily contributed as a new approach of re-thinking in nature, and expressing the massive co-operation between one of the most natural complexity sciences such as; the Biology Science and Architecture in which the biologists are getting their seats at the designing table as well. No information is available regarding the integration between Architecture and Biology especially in terms of both the energy efficiency and the thermal comfort of a building. The paper presents a theoretical basis, and cases study analytical strategies. The Bio-mimetic levels and approaches in Architecture and its advantages when applying in the light of building sustainability and energy efficiency are defined. The Bio-mimicry in cooling and ventilation systems and its relation to the thermal comfort of the building are also been discussed. The East gate building in Zimbabwe, the CH2 building in Australia are analyzed as case studies for the same bio-mimetic selection prototype (the termites’ mound). Summarily, our results provide evidence that each mimicking level achieved in a building can lead to massive financial savings, minimized energy consumption amount, and a better level of thermal comfort as well.

**Keywords:** Bio-mimicry, Termites mound, Breathing structure, Energy efficiency, Thermal Comfort.

**Introduction**

Designers and Architects had sought for biological inspirations in natural sciences especially The Biology Science since the early nineteenth century. They had concerns about imitating the natural solutions and methods in the growth’s processes and evolution in design analogous rather than just imitating the outer forms of plants or animals. The writings of several modern architects had contained a number of influential biological design solutions such as *Le Corbusier* and *Frank Lloyd Wright*. Le Corbusier announced that the Biology Science is to be the greatest inspiring science in Architecture ([Kellert et al, 2011](#)).

However, in the past, the Biological analogy with Architecture was considered to be a sort of a Superficial Analogy. But looking to Biology at a deeper level can easily create a prominent scientific analogy to be a radical source of understanding natural solutions ([Yen et al, 2014](#)). The Current Research in Bio-mimetics; which can be easily defined as (the engineering analysis of an organism or its behavior for applying their principles in the Design
field), gave a new rigor to the development of the bio-technics in the 1920s and 1930s (El Ahmar, 2011).

The term ‘biomimicry’ first appeared in 1962 and developed among scientists in the 1980s (Pawlyn, 2011). Julian Vincent defines it as ‘the abstraction of good design from nature’ (Vincent, 2014), while for Janine Benyus it is a new discipline that studies nature’s best ideas and then imitates these designs and processes to solve human problems. Studying a leaf to invent a better solar cell is an example. It is an "innovation inspired by nature" (Singh and Nayyar, 2015).

In fact, the approaches of Bio-mimicry as a designing process can be easily divided into 2 parts: the first part is to determine the human need or the designing problem, the second part is looking in nature for expectable solutions such as a specific characteristic or a particular behavior or a way of adaptation of an organism and translate that to a designing buildable theme as a first influencing step to the essential solution (Maglic, 2014). The previous approaches require the cooperation of designers and biologists for guaranteeing the perfect match of the biological solution to the designing problem (Maglic, 2014).

Research Objectives

This is an account of a descriptive study of the effect of Bio-mimicry on the energy consumption, and thermal comfort levels. This research aims to shed the light on the integrative approach of thinking regarding the co-operation between the biology Science, and Architecture through Bio-mimicry in order to minimize the energy consumption, and improve the thermal comfort of the space as well.

Research Methodology

The research presents a theoretical basis, and cases study analytical strategies. The East gate building in Zimbabwe, the CH2 building in Australia are analyzed as case studies for the same bio-mimetic selection prototype (the termites’ mound) in order to prove that each mimicking level achieved can lead to massive financial savings, minimized energy consumption amount, and a better level of thermal comfort.

Literature Review

**Bio-mimicry to increase Sustainability**

It is important to note that buildings which follow the Bio-mimetic inspirations can easily reach Sustainability because Bio-mimicry is related to the Life’s principles. The buildings applied these translations can perform well as natural strategies are always effective. They can also save Energy, and minimize Material costs by mimicking the natural shapes; it would be more economical to concentrate the building’s design shape rather than its materials. They can redefine Waste because natural and biological analogs are optimally and automatically managing unnecessary redundancies (Benyus,1997).

Moreover, bio-mimicry is often considered to be a tool for applying Sustainability in the built environment, human products, and materials. However, it is important to highlight on the concept that not all the bio-mimetic technologies are more sustainable, and they may not have been designed for this purpose initially (De Pauw et al, 2015).

**Levels of Bio-mimicry**
There are three levels of Bio-mimicry; the organism, behavior, and ecosystem. The first level is the organism level which can be described as the imitation of a certain organism such as animals or plants, the organism can be partially or totally imitated. The second level is the behavior level which can be described as the imitation of the behavior of an organism or the way it adapts to a larger context. The third level is the Eco-system level which can be described as the imitation of an entire eco-system with its eco-principles that permit the ecosystem to be functioned in a successful way (Fish and Beneski, 2014).

In this quest, we can easily say that under each level of Bio-mimicking nature, there are five sub-levels of imitating (see Figure 1). The first sublevel is the form (what it looks like), the second sublevel is the material (what it is made from), the third sublevel is the construction (how it is made), the fourth sublevel is the process (the steps in which it works), and the fifth sublevel is the function (what it can do) (El Ahmar, 2011).

**Figure 1** The Levels of Bio-mimicry. (Adapted from: El Ahmar, 2011).

**Bio-mimicry (The Behavior level)**

The Behavior level of bio-mimicry can be described as the mimicking of the behavior of a certain organism or maybe the relationships between specific species (Rabbani, 2011). In Architecture, there are powerful convincing examples which are the East gate building in Harare, Zimbabwe and, the CH2 building in Melbourne, Australia. For originating an optimal interior environment with thermal stability, both buildings imitate the techniques of temperature regulation and, passive ventilation in the termite’s mound, (see Table 1), an example of a building that imitates the termites in each of the bio-mimicry behavioral sublevels.

**Table 1** Bio-mimicry – the Behavior level with a description for each sublevel by applying on a building that mimics termites. (Adapted from: Zari, 2007).

<table>
<thead>
<tr>
<th>Levels Of Bio-mimicry</th>
<th>Example - A building that imitates the termites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form</td>
<td>The building resembles a model of a termite mound.</td>
</tr>
<tr>
<td>Material</td>
<td>The building is built using the same materials that the termites use while building their mound such as the digested fine soil for</td>
</tr>
</tbody>
</table>
(Mimicry of the behavior of an organism or the way it associates with its larger context)

<table>
<thead>
<tr>
<th>Construction</th>
<th>The building is been constructed using the same way that the termites used while building their mound, such as piling earth at specific times in certain destinations for example.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>The building works as the termites’ mound did, for example through selection of materials, shape, natural ventilation, and orientation.</td>
</tr>
<tr>
<td>Function</td>
<td>The building’s functions were operated in the same strategy that the termites’ mound functions were been operated, for example, the regulation of the thermal conditions and the thermal stability to be perfect.</td>
</tr>
</tbody>
</table>

**The Case-studies’ proto-type selection (the Termites Mound)**

As for Korb, the mechanism of breathing inside the termites’ mound offers an enormous number of building designs which are inspired by the termites. According to them, there is no need again to be constrained in buildings’ designs by the induced-flow or thermo-siphon flow models. A whole new exploration of wind energy is to be found while studying the matter of how the termites’ mound internally works (Korb 2010).

However, the mechanism of the termites’ mound’s breathing structure can be summarized in the following: the termites’ mound is considered to be a part of a whole integrated system that also includes the subterranean nest, and the termites excavated reticulum tunnels. Both of them can extend through the mound upwards and envelop the nest downwards. Exactly the same as the integrated breathing system of a lung, there are multiple layers which are involved in the function of gas exchange of the colony (Turner, and Soar 2008).

The lung is considered to be a multi-phase gas exchanger. The ventilation phase is described to be only one phase and it occurs in the upper airways of the lung. The upper airways of the lung are the trachea and a variety of branches of the bronchial tree. A forced convection which is operated by the respiratory muscles strongly dominates the gas exchange process in the upper airways. On the other side, the lung’s terminal airways are alveoli and the alveolar ducts (see Figure 2). Diffusion strongly dominates the gas exchange in the terminal airways in which there is no airflow there (Engel, and Paiya 1985).

The same as lungs, where there is an ultimate diffusion phase. The Termites are described to be as mobile alveoli which are responsible for the completion of the diffusion phase inside the mound. The Termites’ nest has consisted of an enormous number of galleries divided by thin walls that are pierced by some large pores (each of diameter 2-3 mm). The termites are embedded in the nest and the nest is embedded in a large reticulum as well. The galleries of the nest are connected to the reticulum through a chimney and this reticulum is connected to the nest as its base (see Figure 3), (Turner 1994).
The substantial metabolism which is concentrated inside the nest powers the air movements inside the whole reticulum. These air movements are strongly dominated by Natural convection. The reticulum includes a large number of vertical surface conduits. The Wind drive the air movements strongly in the egress tunnels and the surface conduits. Commonly, in lungs, the function of the respiratory colony is depended on a mixed phase analogy that took place between the subterranean structures and the mound’s upper parts, where the Natural convection dominates the subterranean structures, and the wind-driven force dominates the upper parts of the mound (Turner 2001).

The lungs and the termites’ mound are both considered to be Air Conditioning systems (AC systems). For example, an Air Conditioning “motor” which is the tidal movement of air drives the Lung’s whole ventilation system. The determination of the function of lungs depends on the depth in which the AC energy can be embedded through the mixed phase regime. Commonly, the function of the mound depends on the depth of the AC energy’s penetration within the mound (Turner, and Soar 2008).

All the previous explanation about some common peculiar functions of the lungs and the mound can be highlighted on the sort of mechanism that both the lungs and the mound mediate the respiratory gas exchange when ventilation doesn’t reach the whole structure. We can easily summarize this by mentioning that ventilation does not have to reach to the entire structure in impedance driven systems, but the AC energy has to penetrate deeply to optimize the mixed phase region which is the gas exchange.

A Comparative Analysis of the East gate building, the Council House 2 (CH2) building as case studies for the same bio-mimetic selection prototype.

First of all, we must mention that choosing these buildings specifically as case studies was on a logical basis. The East gate building in Zimbabwe and the Council House 2 (CH2) building in Australia had been designed by the same designer Mick Pearce, who had chosen the same bio-mimetic approach in the design of both of them. The Termites Mound as a breathing structure was Pearce’s prototype model through bio-mimicking for achieving his challenges both of his projects.

The Projects’ Basic Information
The basic information of each project was mentioned briefly in the following table.

Table 2 The Basic information of the East gate building in Harare and the CH2 building in Australia. (Adapted from: (online), archdaily.com, accessed on 7 May 2018)

<table>
<thead>
<tr>
<th>Points of Comparison</th>
<th>The East gate building in Zimbabwe</th>
<th>The Council House 2 (CH2) building in Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architect</td>
<td>Mick Pearce</td>
<td>Mick Pearce</td>
</tr>
<tr>
<td>Location</td>
<td>Harare, Zimbabwe, Southern Africa, between South Africa and Zambia.</td>
<td>Melbourne, Australia</td>
</tr>
<tr>
<td>Climate</td>
<td>Tropical; moderated by altitude; rainy season (From November to March).</td>
<td>Moderate Oceanic Climate</td>
</tr>
<tr>
<td>Category</td>
<td>Office/Public Building</td>
<td>Office Building</td>
</tr>
<tr>
<td>Area</td>
<td>55,000 m²</td>
<td>12,500 m²</td>
</tr>
<tr>
<td>Year constructed</td>
<td>1996</td>
<td>2006</td>
</tr>
</tbody>
</table>

The Projects’ Detailed Information
The detailed information of each project has been discussed in the following table.

Table 3 The detailed information of the East gate building in Harare and the CH2 building in Australia. (Source: Authors)

<table>
<thead>
<tr>
<th>Points of Comparison</th>
<th>The East gate building in Zimbabwe</th>
<th>The Council House 2 (CH2) building in Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Description</td>
<td>The East gate center is an Office block attached to a shopping center in Harare. It consists of 26000 m² of office space and 5600 m² retail space as well (Turner and Soar, 2008).</td>
<td>The CH2 building is a 10 storey office building of Net available area 9373 m² and Gross area 12536 m² (Turner and Soar, 2008).</td>
</tr>
<tr>
<td>Idea of Architect</td>
<td>The architect Mick Pearce firstly wanted to draw the design’s inspiration theme from Local nature especially the Tropical Architecture.</td>
<td>The architect Mick Pearce here follows the same inspirational theme in the East gate project in addition that the building should express the same way that a natural ecosystem is embedded in its natural location.</td>
</tr>
<tr>
<td>Challenge to be achieved</td>
<td>Creating a self-regulating ventilation system that would keep the building at temperatures that are comfortable by creating an innovative environmental system for heating and cooling.</td>
<td>Creating a self-regulating ventilation system that would keep the building at temperatures that are comfortable for workers and residents by creating an innovative environmental system for heating and cooling in addition to supplying the building with air...</td>
</tr>
</tbody>
</table>
filtration and cleaning system for increasing the indoor air quality.

The Projects’ Bio-mimetic Comparative Analysis

A comparative analysis has been created to show the bio-mimetic approaches used in both of the projects in the following table.

Table 4 A Bio-mimetic comparative analysis between the East gate building and the CH2 building. (Source: Authors)

<table>
<thead>
<tr>
<th>Points of Comparison</th>
<th>The East gate building in Zimbabwe</th>
<th>The Council House 2 (CH2) building in Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-mimetic Approach used</td>
<td>The Termites Mound of southern Africa.</td>
<td>The Termites mound of southern Africa.</td>
</tr>
<tr>
<td>Bio-mimetic Main Level</td>
<td>Behavior Level</td>
<td>Behavior Level</td>
</tr>
<tr>
<td>Bio-mimetic sublevel</td>
<td>Form</td>
<td>Un-mimicked</td>
</tr>
<tr>
<td></td>
<td>Material</td>
<td>Un-mimicked</td>
</tr>
<tr>
<td></td>
<td>Construction</td>
<td>Un-mimicked</td>
</tr>
<tr>
<td></td>
<td>Process</td>
<td>Mimicked</td>
</tr>
<tr>
<td></td>
<td>Function</td>
<td>Mimicked</td>
</tr>
</tbody>
</table>

The Projects’ Bio-mimetic Detailed Analysis

First: The East Gate building in Zimbabwe.

Bio-mimicked Process (Natural-Ventilated Building)

The induced flow principle (see Figure 4), which God creates in the Termites mound is obviously shown in the design of Tall Stacks that open into air spaces that allow the natural ventilation to pass through the building. The building mass can either warm or cool the outside air depending on the hottest of them whether the building concrete or the air. Then the air is vented inside the building through the upper chimneys. The complex has consisted of two buildings separated by a large open space and covered by glass. Air is vented continuously through this open space by fans attached to the first floor. The fresh air replaces the stuffy air that rises to upper ports in the ceilings of each floor. It then enters the vertical ducts before it comes out of the building (see Figure 5).

Figure 4 The induced Flow in open chimney Termites Mound. (Adapted from: Turner and Soar, 2008)

Figure 5 The East gate building’s air convection. (Adapted from: (online) Inhabitat.com, Accessed on 2 May 2018)
Bio-mimicked Function (Thermal control)

As the property of air convection in the Termites mound, the architect took advantage of the thermal storage, night cooling, and the air convection (see Figure 6). The building’s construction material is concrete which has the availability to store the heat for later use. The cool air is driven down to the bottom of the building by the use of large fans, taking the place of the daytime warmer air. This air is driven up to the top of the building through the chimneys. Similarly, the office spaces work in that way pushes the colder air to the bottom of the spaces, which takes the place of the daytime warmer air. By the usage of the convection currents through the wing energy and sunlight, Pearce is able to keep both the atrium and offices at sustained temperature.

![Figure 6 The Termites Mound air convection. (Adapted from: Turner and Soar, 2008)](image)

Air Cleaning and Filtration Analysis

Unfortunately, Pearce here depended on the design of the induced flow system only to renew the indoor air of the spaces by optimal results and rates without any intentions for optimizing the indoor air filtration and cleaning.

Building’s Additional Elements

- There is no direct sunlight at all on the north façade and the external walls of the building.
- For minimizing the energy consumption and heat gain of the building, Pearce intended to achieve a balance between the internal and external light.
- All the windows were sealed to avoid the noise pollution and the unpredictable wind and temperatures depending on the ducted ventilation.
- All the windows have light filters, glare, and noise and security controller in addition to the solar panels which were adjusted for hot water heaters on the top of the building (Atkinson, 1995).

Second: The Council House 2 (CH2) building in Australia.

Bio-mimicked Process: (Natural-Ventilated Building)

- There is a stack ventilation to drive the air at the north and the south of the building. The ventilation stacks in the northern side are black to absorb the heat from the
sunlight that the northern side receives almost during the whole day. This makes the warm air rises up and out of the stacks.

- The vents of the southern side are light colored as this side receives less sunlight so as to reflect the heat and allow the airflow to be cold.
- The ventilation stacks at the top of the building are larger because they are angled. This can easily make the air flow control the natural lighting levels. The largest windows are located at the street level and had the smallest width of the stack. It is noticeable that gradually the designer intended to reduce the sizes of windows till the top of the building where there are the most natural light and the smallest windows with the largest width of the stack.

![Image](https://via.placeholder.com/150)

**Figure 7** Translation of termite mound ventilation to the CH2 building. (Adapted from: (online), Archdaily.com, accessed on 2 May 2018)

**Bio-mimicked Function (Heating and Cooling Systems / Thermal Control)**

The design solution here is adapted from the Termites Mound’s air conditioning system. This approach in thinking resulted in a heating and cooling system which relies on the natural air convection, the stack ventilation, water cooling system and thermal mass.

- *Thermal mass:* The ceiling of the spaces inside the building are made from precast concrete and in a wavy shape to maximize the surface area and the capacity of thermal mass. The ceilings perform the role of the soil inside the Termites Mound. The thermal mass in the concrete is driven at night by a night purge which makes the building spaces cooler. The building opens at night for 5 hours so as to make the building absorb the cool from night air and make it absorb the heat during the day. The collected heated air at the upper of the ceiling is also driven out of the building through the ventilation stacks.

- *The ceiling panels and chilled beams:* the building has been cooled by water cooling system. The beams and panels run chilled water to provide noticeable cooling. The warm air has been driven up and cooled through the chilled panels which drop and make convection current naturally.

- *Phase change material:* The building also uses the phase change material to cool the water for the beams and panels. This can also be called the battery of the building...
because it is responsible for storing the coolness. It aids in keeping the water at the chilled panels and beams at the preferred temperature.

- **Shower Towers:** The outside air is driven above the street level and has been cooled by evaporation through the shower towers that are located on the southern façade. The cool air is provided to the spaces and the cool water’s role is to pre-cool the water that is coming from the chilled water panels.

![Figure 8 Wavy concrete ceilings to absorb heat and keep the internal space cool. (Adapted from: (Online), archdaily.com, accessed on 2 May 2018)](image)

![Figure 9 The shower tower applied in the CH2 building. (Adapted from: (Online), archdaily.com, accessed on 2 May 2018)](image)

**Air Cleaning and Filtration Analysis**

Strategies were made here to improve the indoor environmental quality (IEQ) as the designers created a well designed indoor environment that enjoys natural lighting, fresh air, and use of materials with low amounts of Volatile Organic Compounds (VOCs) (Tan, 2007).

The usage of the displacement ventilation system in the building improved the indoor air quality and raises the operational efficiency in the spaces (Tan, 2007).

The building’s interior is well designed and decorated with various plant lives.

**Building’s Additional Elements**

The following elements were been added for minimizing the energy consumption as (Tan, 2007) mentioned:

- Wind Turbines: For aiding the night purging effectively with 6%.
- Primary Air supply underneath the floor: For minimizing the need for fans and for health benefits as well.
- Semi-closed stairwell: For the ability to get fresh air while flowing among the floors.
- The adjustment of raised floor -200 mm: For guaranteeing the maximum flexibility and the displacement air delivery with low velocity.
- Double skin façade internally closed during the working hours.
- Co-generation: For lower energy consumption, Gas is more efficient fuel in green-housing, and the heat comes from the waste can be used for heating and cooling.
Results & Conclusion

Based on the data that was mentioned in Mick Pearce official website, the results achieved for the East gate building in Zimbabwe through Bio-mimicking the Termites Mound in Behavior level which were as in the following:

- **In terms of financial savings**
  The East gate building had saved about 3.5 million dollars by not purchasing air conditioning system in the first 5 years. Moreover, the building’s ventilation system costs one-tenth that of a comparable air-conditioned building.

- **In terms of energy consumption**
  The East gate building uses 35 % less energy than any comparable conventional buildings in Harare.

Also, based on the data that was mentioned in Mick Pearce official website, the results achieved for the CH2 building in Australia through Bio-mimicking the Termites Mound in Behavior level which were as in the following:

- **In terms of financial savings**
  Twelve million dollars from the total cost of the CH2 building were spent on the sustainable design mechanisms, which resulted in maximizing the worker’s productivity by 10%. In addition to the starting estimated payback for what was spent on sustainable elements in the building that was just under 10 years. However, with the increase in the productivity of workers, the savings were increased and the payback period has been minimized to 6 years. The CH2 building saves 2 million dollars per year which equates the total cost of the building (51.045 million dollars) over 25 years.

- **In terms of energy consumption:**
  The CO2 emissions in the building are 64% compared to a five green star building. The electricity consumption has been minimized by 85%, in addition to the water main supplies which has been minimized also by 72%. The adjustment of new T5 light fittings which consume less energy by 65% and new LCD computer monitors which consume less energy by 77% as well.

- **In Terms of Indoor Air Quality:**
  The formaldehyde concentrations in the air of the CH2 building are lower than any common office building. The air quality indoors is considered to be optimal for the 100% fresh air intake, also the usage of materials with low toxicity, and the noticeable usage of indoor plants as well. The ideal consideration of the ambient noise and reverberation times inside the building’s spaces.
  Thermal comfort inside the building’s spaces is considered to be good.

These previous findings strongly support our research hypothesis which is the positive effect of Bio-mimicry on minimizing the energy consumption, and improving the thermal comfort of the space. Bio-mimicry has significantly succeeded to be a leading designable discipline in nourishing curiosity for obtaining more inherent sustainable schemes into our buildings. So as to this, adopting the idea of the necessarily existence of an appropriate co-operation between the Biology Science, and Architecture especially in office buildings is extremely recommended for more major innovations. Regardless, future research could continue to explore the matter of creating human built systems in office buildings through bio-mimetic strategies that are inherently resilient to disturbances. This provides a good starting point for discussion and further research.
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Tan, S.F., 2007. CH2, 6 stars, but how does it work? [The City of Melbourne's new office building has been designed according to environmental best practice.]. Architecture Australia, 96(1).


Energy efficient prefabricated housing units: Product review and the development of a Cypriot paradigm

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² IMA Architecture.
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⁴ Pricilab Ltd.

Abstract: This paper aims to examine the features and elements that govern the design and construction process of a bioclimatic, smart, prefabricated housing unit. The study is based on a review of the current literature and a taxonomy of current and proposed applications based on different prefabricated building typologies and fabrication methods. The proposed research also aims to evaluate the design implications and the performance of construction and energy components that maximize the unit’s design and energy potential. All cases will be addressed in terms of the challenges faced both by conforming to and enhancing the architectural design concept, as well as by optimizing the overall design performance and minimizing the energy consumption of the building. The paper delves also into the investigation, assessment and categorization of the main characteristics of existing integrated technologies through case studies, analysing the type and the use of each case. Thereafter, an evaluation of the performance of the various typologies under examination is carried out in order to identify the best practices for different applications. Subsequently, a preliminary proposal for a "Prefabricated, ECO Smart Housing Unit", based on local technical knowledge, and the prevalent fabrication conditions in Cyprus, is presented based on the conclusions drawn from the assessment and categorization of previous sections. The ultimate aim of this effort is to critically present the breadth of typologies and the plethora of alternatives that can be applied on a green prefabricated building unit, in ways that maximize its design and energy potential.

Keywords: Prefabricated housing units, Passive Design Strategies, Renewable Energy Technologies, Integrated Technologies, Evaluation Methodology

Introduction

The energy problem is at the forefront of current discussions. After the first oil crisis in the early seventies, the use of renewable sources, especially solar energy integrated with architectural design, is an important parameter in reducing a building’s carbon footprint (Vassiliades et al. 2014). At the same time, the western financial crisis of the last decade had a considerable impact on the housing market, which will continue to be pronounced for a long time, especially on the housing construction market (van der Heijden et al. 2011). In parallel, the speed and ease for the completion of a construction, as well as the implicated financial accessibility, have always been a basic pursuit for the creation of a house. This, is an even greater need in the modern global economy (Panjehpour & Abang Ali 2013).

In this context, housing prefabrication has emerged as a cost and energy-saving solution, which can also be linked to the reduction of environmental impacts, as well as to the development of green construction practices (Boafo et al. 2016). The prefabricated construction method has several advantages compared to conventional construction, since it is based mainly on the standardization of the production methods, the mechanization of the production, transport and execution processes and the systematization of all the works, from the stage of design, to the design and budget of construction, and to the transport,
installation, and assembly of its components. In Cyprus, the current prefabricated building stock consists mainly of some warehouses and other supporting buildings, while their use as a permanent residence is at a very low level.

**History of prefabrication**

The first attempts for prefabrication date back to the 16th century, along with the British efforts to colonize America, New Zealand, Australia and Africa. The lack of familiarity with the local building materials and techniques, required the construction of the various buildings in England and their transportation to the desired location. The history of prefabrication can be divided into three main periods (Panjehpour & Abang Ali 2013): before, during and after the Second World War.

During these time periods there were several examples of prefabricated applications. The demand for prefabricated housing increased during the Second World War, when the United States government alone created 850000 such homes for its soldiers in less than 2 years. After the war, interest in prefabrication increased even more towards the out-of-field construction and the transportation of parts to the building location.

The capabilities of prefabrication preoccupied even the great architects of the time, such as Frank Lloyd Wright, who in 1936 designed a system of standardized details and repeating units for prefabricated residences. Later, in 1945-1948, William Levitt managed to achieve mass production rates, reaching 150 prefabricated houses per week.

In 1976 in America, the separation of prefabricated from permanent residences designed in accordance with the requirements of the International Building Code (IBC) was legally established. In 1996, IKEA introduced prefabricated houses, of traditional type, in Sweden (Panjehpour & Abang Ali 2013).

In 2015 in Changsha, China, the skyscraper "Mini Sky City", of 57 floors and 800 apartments, was completed in 19 working days using prefabricated parts and methods. The 2736 units of the building were under production for 4.5 months before the onsite start of construction work (Boafo et al. 2016).

In general, rapid advances in the field of prefabrication, such as sustainability, cost / performance or energy and time savings, took place at the dawn of the 21st century (Panjehpour & Abang Ali 2013).

Nevertheless, the prefabrication industry in Cyprus has been a very slowly growing market. Specifically, there is a limited number of companies (close to 12) that are exclusively engaged with low cost and quality small residences and offices, warehouses and other supporting buildings which made their appearance in the early 1990s (Anon 2015; Anon 2017).

**The Case of Cyprus**

The building prefabrication in Cyprus is in an early stage of development. This is evident from a statistical survey conducted by (Michael et al., 2015), which is based on data obtained by questionnaires filled by companies exclusively engaged in building prefabrication. The questions relate to the average number of sales, the preferred type / use of construction, the cost and the required delivery time per use, as well as the preferred size of the housing units for the years 2011-2014.

It is noted that the dominant uses are offices and supporting buildings, while housing categories follow in preference (Figure 1). In the housing sector, the evaluation of the questionnaires shows that in 2011 each company proceeded with the construction of an
average of 17 permanent, or occasional housing units, an average of 12 in 2012, an average of 9 in 2013 and an average of 10 in 2014. The differentiation noticed in sales in 2012-2014 compared to 2011, is the result of the overall economic crisis in Cyprus.

The average cost and delivery time of prefabricated buildings’ manufacturing is 560 euros per sq.m. and 5.5 weeks for permanent houses respectively, 490 euro per sq.m. and 5 weeks for occasional houses, 350 euro per sq.m. and 3.5 weeks for offices and 300 euro per sq.m. and 3 weeks for warehouses and supporting buildings (Figure 1).

The preferred size of prefabricated housing units by Cypriot buyers (Figure 1) is about 50-75 sq.m. per housing unit, followed by the housing units of about 75-100 sq.m.. The research presented above, shows among others, that there has been a slight increase in the demand for prefabricated housing units in Cyprus, because of the economic crisis (Michael et al., 2015). However, the demand levels for a prefabricated housing unit
still remains at very low levels and consists 1.5% of the conventional housing units’ demand levels (Anon 2015).

State of the Art – Literature Review

Prefabrication is a specialized manufacturing process, where various materials are composed to form a component of a structure, such as a residential unit (Reed et al. 2012). The main construction work takes place in a different location from the building location, the mass production is tailor-made according to the needs and the financial capabilities of each user, and the production processes are fully digitized with the use of computerized manufacturing systems because of the rapid technological developments of the last decade (Panjehpour & Abang Ali 2013).

Although there are plenty of prefabricated applications, related literature remains rather limited. The first research on modern prefabricated houses was presented in the book “Prefab” by Allison Arieff and Bryan Burkhart (Arieff & Burkhart 2002). At least until 2013, there were no organized studies relating to the ecological aspect of prefabrication, on how the technology of the so-called "ecological housing" could be shifted via sustainable methods into the prefabricated housing technology (Panjehpour & Abang Ali 2013).

According to Boafo et al. (Boafo et al. 2016), there are four main Prefabricated Building Concepts in terms of Degree of Prefabrication; namely, the Components, the Panelized structures, the Modular structures and the Hybrid structures.

The degree of prefabrication refers to the size and complexity of the prefabricated parts or the configuration of the finished product. By reducing the size of the prefabricated elements, the degree of on-site construction labour increases and vice versa.

The characteristics of a prefabricated house are, in their majority, the same as a typical house, i.e. following the relevant legislation. In terms of the energy efficient prefabricated housing units, these characteristics need to be aligned with the characteristics of green buildings. The majority of existing studies focus on the comparison between the characteristics of green buildings and those of conventional buildings such as energy efficiency, water efficiency, indoor environmental quality, thermal comfort, health, and productivity (Zuo & Zhao 2014).

In relation to the environmental aspect, green buildings should help to improve the urban biodiversity and protect the eco-system by means of sustainable land use (Henry & Frascaria-Lacoste 2012; Bianchini & Hewage 2012) as well as through the reduction of construction and demolition waste (Akadiri & Olomolaiye 2012; Yeheyis et al. 2013). At the same time, the recycling rate - reused and recycled materials in new buildings, has to be above 90% in order to achieve the mitigation of the environmental impacts of construction and demolition waste (Coelho & de Brito 2012). In general, green buildings must be more energy efficient, more water efficient and contribute to the reduction of carbon emissions, compared to conventional buildings (Zuo & Zhao 2014).

Economic speaking, the financial modelling showed that LEED certified buildings will incur some 10% of extra cost (Ross et al. 2007). However, this is counter argued by studies that show that green buildings can save up to 30-55% of more energy consumption than conventional buildings (Anon 2004; Lau et al. 2009).

The human aspect is another factor related to green buildings. This is because there is a number of other non-cost related benefits associated with green buildings (Zuo & Zhao 2014). One of these benefits is thermal comfort which is the result of the complex dynamics of temperature and humidity and it is closely related to the satisfaction of building users.
(Zhang & Altan 2011; Mekhilef et al. 2012; Bisoniya et al. 2013). Another advantage of a green building in terms of human aspects, is the achievement of indoor environmental quality (IEQ) (Zuo & Zhao 2014) which features in all leading green building assessment tools (Yu & Jeong Tai Kim 2011).

**Methodology of investigation**

The proposed methodology, to formulate a classification and taxonomy of various existing prefabricated housing units, relies on the literature and state of the art review and previous analysis. The fifty case studies selected, provide a sample for a taxonomy that delves into the investigation, assessment and categorization of existing prefabricated housing unit systems and characteristics. The selection of these fifty case studies was based on their environmental characteristics. Basic criteria for selected case studies including having some architectural interest, and at the same time to have applied at least one green strategy, either active, passive or ecological. In each case, the units’ characteristics are examined in order to identify the specifications of the various applications and juxtapose them in a table format according to their type (modular, prefabricated elements, and container). This juxtaposition of these characteristics, rather than their effectiveness, is preferred as it serves the ultimate aim of the research which is to critically present the plethora of alternatives that can be applied on a green prefabricated building unit, in a way that they will create a general design framework for the design of a prefabricated residential model. This general design framework will then enable the designer to focus on the specific local characteristics (climatic, economic and cultural) of each area, which will determine the final design strategy.

The analysis of green buildings introduces the main juxtaposition of the energy efficient prefabricated housing units’ characteristics. The taxonomy starts with the building management systems (BMS). Subsequently, it is checked whether the building can be autonomous and operate off-grid. Then, the environmental aspects are presented. Afterwards, the building’s construction aspect is analyzed. Subsequently, the structural types and finally, the sitting adaptability types are presented.

**Comparative assessment and critical evaluation of energy efficient prefabricated housing units**

**Best Practices**

In order to cover all the major applications addressing energy efficient prefabricated housing units, 50 case studies were examined (14 modular, 30 prefabricated elements, 6 container). In these case studies, 46 types of different characteristics are examined on the three aforementioned types of prefabricated units. Some characteristics are more "popular", while others are seen in a limited number of examples.

In the case of the Modular type, the structure is built off-site, either as a single unit or as a small number of different components that can be assembled only in a single way (see Figure 2).
In the case of the Prefabricated Elements type, the building is built either on or off-site, as a number of assembled components (see Figure 3).

In the case of the Container type, the building is built either on or off-site, and its main unit is based on a partially modified shipping container (see Figure 4).

**Taxonomy of energy efficient prefabricated housing units’ characteristics**

The organization of the table below (Table 1) is based on the differentiation of the three main types of the units, which are then organized according to the features mentioned above. There is also a column where the total number of times each characteristic is traced in the case studies, ranking them in terms of popularity. These arithmetic concentrations of characteristics show their popularity within the broad sample of environmental characteristics, thus making some kind of quantification of their significance during the design.
Table 1. Comparative table between the characteristics of all types of energy efficient prefabricated housing units.

<table>
<thead>
<tr>
<th></th>
<th>Modular</th>
<th>Prefabricated</th>
<th>Container</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMS</strong></td>
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<td>Monitoring</td>
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<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Control</td>
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<td>1</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Manual</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td><strong>Off Grid (Autonomous)</strong></td>
<td>6</td>
<td>8</td>
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<td>16</td>
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<tr>
<td><strong>Active Systems</strong></td>
<td></td>
<td></td>
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<tr>
<td>PV</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>Integrated</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>STS</td>
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<td>1</td>
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</tr>
<tr>
<td>Applied</td>
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<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Integrated</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<tr>
<td>Direct Solar Gains</td>
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<td>40</td>
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<tr>
<td>Natural Ventilation</td>
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<tr>
<td>Shading Systems</td>
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<td>22</td>
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<td>34</td>
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<tr>
<td>Evaporating Cooling</td>
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<td>0</td>
</tr>
<tr>
<td>Natural Lighting</td>
<td>13</td>
<td>30</td>
<td>6</td>
<td>49</td>
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<tr>
<td>Water Harvesting</td>
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<tr>
<td><strong>Building Physics</strong></td>
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<tr>
<td>Thermal Mass</td>
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<td>5</td>
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<tr>
<td>Thermal Insulation</td>
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<td>Air Tightness</td>
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<td>18</td>
<td>5</td>
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<tr>
<td><strong>Passive Systems</strong></td>
<td></td>
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<td></td>
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<tr>
<td><strong>Ecology</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Recyclable Materials</td>
<td>8</td>
<td>17</td>
<td>6</td>
<td>31</td>
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</table>
Subsequently, each type is examined according to its BMS system, which is analyzed into two subcategories depending on whether they are monitoring or controlling (automatic or manual) systems. Then, it is checked whether the building can be autonomous and perform off-grid.

The first of the subsequent categories is the environmental aspect. Specifically, this aspect is analyzed in three main subcategories: the active systems (biomass, wind, geothermal and solar – PV, STS and hybrid), the passive systems (direct solar gains, natural ventilation, shading systems, evaporating cooling, natural lighting, water harvesting and building physics - thermal mass, thermal insulation and air tightness) and the ecology (recyclable materials, water reuse, green roof / walls). Construction is also examined, which addresses the building materials (masonry, concrete, metal, wood, synthetic) and the methods of construction (permanent or movable, unit or a kit of parts, expandable – in terms of unit and/or cluster, and whether it has a customization potential – reversible or irreversible). There follows an analysis of the structural system of the building, analyzed in four main subcategories: the post and beams system, the balloon framing system, the self-supported system and the load bearing masonry. Finally, the comparative table looks at siting adaptability issues, which is analyzed in four main subcategories: seaworne / floating, on surfaces, on stilts and underground.

Discussion – Conclusion

The research and the below results below indicate that the development of energy efficient prefabricated housing units is possible. It is also evident that the dominant type of energy efficient prefabricated housing units involves the use of prefabricated elements, followed by the modular type and the container type. This can probably be explained because the use of prefabricated elements can be more affordable due to their easier production process if compared to the other two types which have more limitations in that field, as they are not very easy to produce and build.

Overall, the comparison reveals that the most popular characteristic is the use of natural lighting by the buildings. This is followed by natural ventilation, thermal insulation, and exploitation of direct solar gains, with all of them included in the “passive systems” subcategory. On the contrary, evaporating cooling, which is in the same sub-category, is not used by any unit. Equally common is the irreversible customization potential of the building units, as well as their expendability in a cluster; both of which included in the “construction/methods” sub-category. Another important finding is that the majority of selected case studies do not have a BMS system, while only 16 out of 50 can perform off-grid. It is also remarkable that most of the units use some kind of active system. It is notable that building integration is not popular, and it is met only with the use of PVs. At the same time, it is noted that none of the units use biomass or any type of solar hybrid system. The use of recyclable materials in 31 of the case studies is evidence of their popularity in use. In relation to the other construction characteristics of an energy efficient prefabricated housing unit, the most widely used material is wood, followed by metal and synthetics. The less popular material is masonry, which is not met in any of the examples. It is also observed that most of the units are movable and they are constructed with the use of a kit of parts. It is also noteworthy that the units use a variety of structural systems, with the balloon
framing system and the self-supported system being the most popular. Finally, it is clear that the majority of the units are sited on horizontal surfaces / slabs.

When examining the typologies related to the prefabrication archetypes, one finds a discernible correlation between said archetypes and the totals observed. However, there are some variations, like in the case of BMS, whereby none of the containers have such a system. Another important finding arises from the active systems sub-category, where 6 out of 14 modular units have a building integrated solar system. In the passive systems sub-category, it is observed that none of the containers can provide thermal mass. Additionally, there is no container type using concrete, or any other type, that can have a reversible customization potential. The only structural system used is the self-supported system, while all the cases are sited either on the surfaces or stilts. This variation of the container characteristics is primarily due to the limited number of examples. However, there are some cases, such as the example of the thermal mass, which the container cannot provide for because of its structure.

The present research delimits the main characteristics of energy efficient prefabricated housing units. A fundamental classification and taxonomy of the current state of the field was performed, aiming to create a tool for a deeper understanding. Ultimately, the results can be used as a tool in the initial design process for the design and construction of such a building.

Further research

Based on the research presented in this paper, the research team is working on a new prefabricated residential model, the Prefab ECO - SMART house, which follows an environmental design based on the principles of bioclimatic design and offers minimization of energy requirements and thus energy saving. As a result, the new prefabricated housing unit will be superior to the conventional prefabricated housing units, in terms of cost reduction during its operation.

In addition, the Prefab ECO - SMART house is a pioneering proposal and quite unique in the field of prefabricated housing in Cyprus. Its originality, compared to comparable units internationally, lies on the selection of its construction materials, the environmental design parameters it conforms to, and the automated systems used for the thermal comfort of the users. Finally, other advantages of the unit, compared to other conventional prefabricated units, include the reduction of construction, maintenance, and operation costs, as well as its ability for easy configuration and expansion.

References


Comparative Study of Daylighting Performance for single Vs. Double Skin Façade Office Building for hybrid Ventilation: A Simulation analysis of Two Case Studies by design-builder software

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Abstract: The research aims to investigate that a shading devices combination within double skin facades (DSFs) could not only decrease direct solar heat gain but also shows that shading device configuration has the main impact on the air temperature, thermal comfort and the annual energy consumption in a DSF air cavity but also to maintain the balance of hybrid ventilation. Based on two case studies of an office building; the first with Single Skin Façade (SSF) and the second with Double Skin Façade (DSF); the impact of double skin façade on lighting performance is examined within typical summer conditions in hot arid one like Egypt using Energy Plus. The simulation was applied to the south facade to test significant effects of double skin façade on illuminance values. Simulation results show that a DSF can achieve high lighting performance with better energy efficiency than an SSF; also the basic characteristics of width of the cavity and the shape of shading devices (vertical or horizontal) are examined simulated, while it was concluded that horizontal shading devices at 90-degree angle were more effective to reduce the energy efficiency at south facade by 6.4% and also increase thermal comfort inside the spaces. Comparing the single and double skin facade, the area percentage of the office space with at least 200 to 2700 lux is found in a range of 10%, 50% respectively.

Keywords: Double Skin Façade, Single Skin Façade, Solar heat gain, Hybrid Ventilation, Energy efficiency.

Introduction
The form and construction of facade systems have a strong influence on both the energy consumption of a building and the comfort level of its occupants. A double window system (DWS) is an energy-efficient envelope system in which a cavity is placed between the inner and outer layers to provide natural ventilation, solar radiation control, and enhanced insulation (Ghaffarian, 2012). The DWS is a box-type double-skin facade that is also effective in reducing heating and cooling energy consumption (Fallahi, et al, 2010). In addition, buildings with double-skin facades offer better thermal comfort in the winter and lower thermal amplitude during the summer (Huckemann, et al, 2010). Compared to single-skin facades, the double-skin facades used in South Korea reduce energy consumption during the hot and temperate seasons without any additional energy input.

During the cold season, they require proper operation of their shading and natural ventilation devices to successfully reduce energy consumption (Joe, et al, 2010). The operation of the double-skin facade can influence the energy performance of the buildings (Gratia, et al, 2010). The greenhouse effect in the cavity in the east and west facades may increase heat stress to the internal space, thus, appropriate natural ventilation control is required (Gratia, E, et al, 2010). The results of previous investigations indicate that the application of natural cooling strategies is important in buildings with double skins (Saelens, et al, 2010).
This study focuses on the cooling load reduction effect and daylighting performance of the DWS with a shading device that has selective surface reflectivity that operates a cooling energy reduction focused mode in highly glazed residential buildings. To evaluate the performance of the DWS, a comparative energy simulation is performed. Single window (SW) and double window (DW) systems are selected as the conventional window systems.

Research Problem

The problem addressed by this study is that office spaces have certain environmental requirements to assure that occupancy can perform mental tasks in appropriate ways. These requirements include natural ventilation, daylight distribution, heat gain, air quality, and humidity; sometimes these requirements contradict with each other.

Office buildings are building typology that requires efficient lighting conditions in term of sufficient daylight quantity and efficient daylight quality. Two problems can be outlined, the first problem caused by lacking quantity of natural daylight, that cause high rates of energy consumption due to used artificial lighting alternative. The second problem caused by extra daylight that causes an inefficient unsatisfactory distribution of daylight in working spaces that cause areas that are too darken and other that are too bright accordingly an extra glare of daylight exist, beside a relative increase in solar gain. These two problems forces occupants to fully close their shading system and use artificial lighting to avoid direct sunlight and glare and accordingly cause an increase in energy consumption.

Research Hypotheses

In Office buildings, lighting comfort and energy consumption are significantly enhanced using double skin façade. This can be overcome by breaking up sunlight either by reflecting it on to the ceiling or by diffusing it through baffles. Double skin façade is tested to overcome such obstacles.

Objectives

This work is planned to achieve the following objectives:

To study the performance of shaded DSF applied to offices and determine vital parameters that influence its operation.

To study the influence of cavity’s integrated shading devices on the system performance, and determine critical parameters/characteristics of these devices and how the interaction of different parameters/characteristics could influence the device’s role.

The research aims to compare benefits and examine the technical aspects of DSF technology and base case without DSF.

What is the impact of using double skin facade as construction style on the energy usage, Air Temperature and PMV SET or needs by the building?

This study also uses computer simulation software (Design Builder). This software uses Energy plus Engine for calculating a simulation (Cockcroft, 2015). A validation of the software is discussed in the methodology paper.

Definitions and History of Double Skin Facades

Double-Skin facade is a system consisting of two glass skins placed to provide the intermediate cavity free-flowing air. The cavity ventilations can be mechanically or fan
supported or natural. Air origin varies based on the climatic condition, location, the HVAC strategy, whether the building is occupied at the time or not, and the building utilization. At a distance of 20 centimeters up to two meters the glass skin can be single or double glazing units. Solar shading devices are placed inside the cavity for protection and heat extraction reasons during the cooling period. Double-Skin Facade is associated with various active envelopes, twin facades or second skin facades (Saelens, 2001). It is a facade that is comprised of an inner and outer skin (Gan, 2005).

Advantages and Disadvantages of DSF:

DSF, as a sustainable solution, has advantages and disadvantages at the same time. Thus, for a successful implementation, it is highly important to ensure its suitability to the proposed building and specific location (i.e. climate).

Advantages of DSF: Well-designed DSF can offer many benefits (Pasquay et al, 2004), including:

- Providing a thermal buffer zone and pre-heating air in winter,
- Protecting the integrated shading elements,
- Reducing summer cooling loads,
- Reducing the external noise,
- Possibility of night-time cooling and natural ventilation
Filtering ventilation-air,
- Providing an aesthetic, modern and attractive architectural appearance; and
- Indicating the openness of users and inside functions through the high transparency.

Equally important, proper use of DSF would greatly enhance the indoor daylighting (Hamza et al, 2007), which would save energy for artificial lighting. In additional, it is highly expected that occupant psychology, behaviour and productivity would be enhanced with the installation of such systems as it provides direct and comfort visual continuity to outdoor environments.

**Disadvantages of DSF:**

On the other hand, several undesirable effects might result with DSF application, which are caused by either improper poor design or inefficient operation. These common cons are (Chen, 2010):

- Possibility of summer overheating,
- Increasing undesirable inner-acoustics,
- Possibility of high moisture levels,
- Raising the risk of fire expansion; and
- Maintenance and cleaning difficulties.

In addition, some other facts are still obstacles in front of wide expansion of this application; these include waste-areas of spaces (perimeters), needs for detailed technical design and high capital cost with additional running cost.

**Geometrical Shape of Individual Cavity-integrated Shading Device:**

However, some researches indicated the importance of geometry of slat-unit in addition to its surface’s characteristics to system’s performance (Manz and Frank, 2005). For instance, DSF with curvature Venetian blinds were modelled using CFD (Ji et al., 2007). Geometrical parameters including thickness (tb), width (d), offset (P) and inclination angle were considered as shown in Figure 4.2. However, all parameters were constant except inclination angle varied throughout the study.

![Figure 3. Geometrical Parameters of DSF cavity integrated devices. Source: (Ji et al., 2007).](image-url)
Solar shading

The issue of solar heat gains becomes critical in determining the cooling load or ventilation rate in a building, to offset the total internal heat gains in order to achieve thermal comfort for occupants. Solar heat gains comprise direct solar beams, diffuse sky solar radiation and reflected radiation. Solar shading devices can be used to block solar beam and solar radiation before they hit on building envelopes, and should be applied to the entirety of a building (Fig. 19) Shading for windows is especially crucial, too. Such devices not only serve in heat gain mitigation but also increase the visual comfort, daylighting and airflow through windows in buildings, and therefore also have to be taken into account.

Figure 4. An example of building shading from the roof of a house in Kuala Lumpur, Malaysia, designed by architect Ken Yeang. Source: Ken Yeang Architect, “Roof-roof House in Kuala Lumpur, Malaysia.”

Solar shading devices can be divided into fixed and moveable types, based on their manner of operation. Moveable shading devices, for example, allow for higher flexibility and increased efficiency in operation, and can be manually or automatically operated. Automatic operation enables real-timely response to dynamic changes in direct solar beams, diffuse and reflected sky radiation.

Solar shading devices can be further classified as overhangs (horizontal) or fins (vertical), and by the various screen styles (brise-soleil, egg-crate…) shown in Figure 20, based on their configurations. Overhangs used on south-facing windows are effective with buildings located in the northern hemisphere, and vice-versa. Fins, on the other hand, are more effectively placed on east-facing and west-facing windows, where overhangs would otherwise have difficulty in blocking low attitude angle solar beams in the early morning or late afternoon. Screen-style solar shading devices combines the qualities of both overhangs and fins, to effectively control direct solar beams at a wider range of latitude and azimuth angle of the sun (Fig. 21).

Figure 5. Examples of different window shading devices. Source: CIBSE, “Energy Efficiency in Buildings: CIBSE Guide F.”
One of the traditional architectural features in Egypt and Middle East to reduce solar heat gain and diffuse natural light is Mashrabiya. Mashrabiya is the Arabic term given to a type of projecting window enclosed with carved wood latticework located on the second storey of a building or higher, often lined with stained glass. In vernacular Arabic architecture, the Mashrabiya serves several functions as shade against the sun and natural ventilation and privacy.

The Mashrabiya was initially intended as a place to cool drinking water, achieving this by enabling a convective cycle that moved air masses from a zone of high pressure to that of low pressure. The Mashrabiya gradually developed into an architectural feature which served not only to encourage airflow and passive cooling, but also to decrease solar heat gain and to diffuse natural light that penetrated through openings (Stouffs & Sariyildiz, 2013).

Nowadays, screens are often integrated in the building envelope. With advance technologies it is possible to build these structures in the affordable ways. Some of the available methods of constructions are scatching, miling, plasma and lase cutting and fluid forming (Lang & Bader, 2011). A modern version of Mashrabiya can integrate into double skin façade system. A layer of shading screen can install on outer side of fully glazed façade. However unlike double skin façade system, the outer layer is shading screen which does not have any impact on natural ventilation and the focus is on provision of shading as a means of solar avoidance and environmental control. The solar control offered by this modern
interpretation is more complex and a focus on solar avoidance makes it easier to quantify the benefits (Boake, 2014). So by eliminating the issues with buffer zone ventilation, impacts of shading screen on solar avoidance will be easier to quantify.

**Research Methodology**

Inductive method is used; with comparative analysis of daylight performance of two different façade design strategies, a single skin base case is compared against double skin base case. The simulation will be conducted with the aid of "Design-Build" software tool as shown in Fig. 9 which is mainly dependent on (Energy Plus). The investigated aspects: energy consumption, air temperature and daylighting indices and simulation processes are described for each air cavity width start from 0.5m, 1.0m, 1.5m, 2.0m & 2.5m.

![Figure 8](image-url)

**Figure 8.** (a) Base Case; (b) 0.5 m; (c) 1.0 m; (d) 1.5 m; (e) 2.0; (f) 2.5 C.DSF.

**Weather data file**

The weather data file used for this study is EGY_AL QAHIRAH_CAIRO INTL AIR PORT _ETMY.stat.

**Table 5. Details of Weather Data File used for simulation.**

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<thead>
<tr>
<th>Weather Data File</th>
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<td>Source</td>
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</table>

![Figure 9](image-url)

**Figure 9.** Set-points adaptation (18°C-24°C) & Façade Glazing System adaptation, Design Builder Screen shot.
General office building design data

Table 2. Office Building Architectural Data.

<table>
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<th>Building type</th>
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<tr>
<td>Building floors numbers</td>
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</tr>
<tr>
<td>Typical office floor height</td>
<td>4.0 m (slab to slab), 3.70 m ~ 3.0 m (clear height)</td>
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<tr>
<td>Ground floor area</td>
<td>15.0 m 15.0 m = 225 m²</td>
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<tr>
<td>Ventilation system</td>
<td>For &quot;Base-Case&quot; building: Artificial Mechanical ventilation (Full HVAC) system. -For V.DSF building: 'Mixed-Mode' (Hybrid) system all of the year.</td>
</tr>
</tbody>
</table>

Daylighting data

Daylighting simulation is also processed on the air cavity depth to assess the existing situation. Daylighting settings are adjusted according to LEED v.2.2: CIE overcast sky (10,000 lux). (Attia, 2012).

Figure 10. Baseline summary of illumination and Daylight Factor distribution for base case & 0.5m DSF, processed by Design Builder with Radiance engine

Figure 11. Baseline summary of illumination and Daylight Factor distribution for 1.0 m DSF & 1.5 m DSF, processed by Design Builder with Radiance engine
Figure 12. Baseline summary of illumination and Daylight Factor distribution for 1.0 m DSF & 1.5 m DSF, processed by Design Builder with Radiance engine.

The daylight penetration in Figure 10 produced by Design Builder simulation modelling, shows that 70% of the floor receive adequate daylighting to perform office related tasks almost between 768 – 4374 LUX for the base case while 0.5 m DSF achieve 137 – 2711 LUX, 1.0 m DSF achieve 219 – 2615 LUX, 1.5 m DSF achieve 96 – 2672 LUX, 2.0 m DSF achieve 105 – 2715 LUX and 2.5 m DSF achieve 113 – 2699 LUX. However, the base case arises to the remaining 75% of the floor as it receives over 4374 LUX, which means that these areas will suffer from glare issues or at least receive excessive daylighting that don’t add to any benefit to the required LUX levels to perform office related tasks. On the contrary, it may cause the office environment to be uncomfortable to perform the need tasks.

RESULTS AND FINDINGS

The annual energy consumption of each Corridor Double-Skin Façade configuration examined within the office area of the building, in order to determine which Double-Skin Façade configuration and cavity airflow system is achieving the highest degree of efficiency in relation to energy consumption.

![Graph showing Zone Sensible Cooling kWh across different months for various DSF configurations.]

Figure 13. Monthly results of Zone Sensible Cooling kWh of office building with a Variables Cavity of DSF.
Results show that Corridor Double Skin Façade with a 1.5m cavity is the most efficient façade construction combination evaluated, this combination achieved an annual energy consumption value of 10134.55Kwh in June which increase in efficiency of approximately 50% as opposed to the base model utilising a conventional single-skin façade 15189.12 kWh.

![Operative Temperature °C](image1)

Figure 14. Annual results of air temperatures of Base-Case & Ventilated Double Skin Façade Model.

Results also showed that annual air temperature of Single Skin Façade (SSF) was higher than other alternatives with an Double skin façade (V.DSF) model, the graphical analysis shows that the air temperature with 2.0m ventilated corridor DSF achieved best enhancement while 0.5 &1.0m corridor ventilated DSF increases air temperature equal to the base case model which have a highest air temperature.

![Pierce PMV SET](image2)

Figure 15. : Annual results of Pierce PMV (SET) of Base-Case & Ventilated Double Skin Façade Model.
Figures 15 show the annual Pierce PMV (SET) values for different façade alternatives that Corridor DSF with 1.5m air cavity façade have better thermal comfort condition than BASECASE model.

**Results of Simulation Model analysis**

The research aims to show that a shading devices combination within double skin facades (DSFs) could not only decrease direct solar heat gain but also shows that shading device configuration has the main impact on the daylighting, the air temperature and the annual energy consumption in a DSF air cavity but also to maintain the balance of hybrid ventilation. Based on two case studies of an office building; the first with Single Skin Façade (SSF) and the second with Double Skin Façade (DSF); the impact of double skin façade on lighting performance is examined within typical summer conditions in hot arid one like Egypt using Energy Plus.

The simulation was applied to the south facade to test significant effects of double skin façade on illuminance values. Simulation results show that a DSF can achieve high lighting performance with better energy efficiency than an SSF; also the basic characteristics of width of the cavity and the shape of shading devices (vertical or horizontal) are examined simulated, while it was concluded that horizontal shading devices at 90-degree angle were more effective to reduce the energy efficiency at south facade by 6.4% and also increase thermal comfort inside the spaces. Comparing the single and double skin facade, the area percentage of the office space with at least 2672 to 4374 lux is found in a range of 10%, 50% respectively.

Ventilated double skin façade (V.DSF) type, especially which depends on "Mixed-Mode" ventilation of both: [Natural & (HVAC) system] ventilation strategy considers the most Suitable, Economic application of (DSF) types in "Hot-arid" climatic zones such in Egypt. The simulation results for Double Skin Facades in relation to its effect and compared to single glass facades, preforming under multiple conditions and scenarios. DFS systems usage gives the hope to attain solutions that solves several problems such as the following but not limited to it:

- Both daylighting and mixed mode ventilation are critical climatic control components that should be considered for all building sticks in efforts to reduce energy consumption and to increase the sustainability.
- Reduction of energy consumption (usage of cooling load).
- Confirmation that daylighting penetration is still achievable.

**Air-Cavity width impact** : "Air-Cavity" width: The larger "Air-Cavity" width, the lower energy consumption (but with little rate in reduction) after (50 cm) width.

Medium "Air-Cavity" (1.5) cm width is the most suitable air width, Finally Large type (>200cm) which wastes a functional and valuable impact of ventilated double skin façade.

**Recommendations for future research**

Searching in the domain of 'design-economics' of including "Photo- Voltaic"(PV) panels within the External skin of (V.DSF) in achieving the maximum (Passive/Active) benefits solar radiation.
Model refinement and additional features: Describing of computational models are necessary to supply more dependable and representative thermal performance of DSFs. Enhance zoning for air distribution investigate, perfect design and positioning of shading devices within the cavity may have a major impact on the overall airflow resistances created and subsequently on the resultant on ventilation strategies.

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The Investigation of Scheduled Evaporative Cooling for a Sustainable House Model in Riyadh

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Abstract: Architecture shouldn’t restrict, but reflect the wise and conscious practice of architects towards sustainability. As one of the harshest climatic conditions, Riyadh, the fast-developing capital of Saudi Arabia, stands as one of the challenging environments for architects to deliver competitive and social-responsive concepts, while achieving energy efficiency and environment friendly principles. This study aims to investigate the thermal and energy performances of a contemporary conceptual form for residential villa in hot-arid climate. By exploring different passive strategies including natural ventilation and daylighting, in addition to evaporative cooling, this paper is verifying the architectural decisions of recalling the court-yard, and the introduction of sloped-roof attic concepts to the modern house design in Riyadh. A detached single-family villa is used as case study. After satisfying Saudi national building codes and ASHRAE 62.2 standards, the utilization of indirect-scheduled evaporative cooling is investigated using DesignBuilder software tool. Integration with other strategies and the HVAC system is attempted by investigating their impact in terms of sources efficiency, environment consciousness and social effectiveness. Added to the social values of the private semi-exterior areas, the introduced ventilated glazed-shell court and unoccupied roof showed potential decrease in the annual energy consumption by almost 40%.

Keywords: Evaporative Cooling, sustainable house, hot climate, natural ventilation

Introduction

Among the factors affecting the architecture practice in a specific region, climatic condition is major one. Specially in extreme condition such as hot-arid climates, climatic design principles are crucial. Climatic or environmental design is more toward creating a harmony between the architectural element and the surrounding. While vernacular architecture can be defined as the practice of optimizing the use of natural resources in buildings, mainly sun and wind (Bodach, S. et al. 2014). Many studies confirmed that potential energy saving through an optimized design process, minimizing the heating and cooling loads, is usually more influential than the use of innovative HVAC solutions (Rodriguez-Ubinas, E. et al., 2014). Riyadh, the capital of Saudi Arabia, is one of such regions which has very dry climate, while experiencing temperatures as high as 47°C (Wetherbase, 2011). Although people there had been practicing vernacular architecture for decades, such as courtyards, mud houses etc., the modern practice in architecture lacks conscious effort in using passive methods of controlling the indoor environment. Excessive use of modern materials irrespective of their efficiency in regulating the indoor environment has often resulted in high energy consumption, leading to many environmental problems (Dili, A.S. et al. 2010). Recent statistics shows that residential sector consumes almost 50% of the energy produced in KSA in 2013. Moreover, a house model in Riyadh showed that around 74% of the energy goes to heating and cooling purposes only (Alghoul, 2017). Thus, with the global trends towards sustainability, architects have to be initiative and innovative to design social responsive concepts, while approaching energy efficiency and environment friendly architecture. However, considering the current market
status and sustainability applications in KSA, different models have to be developed to deliver the sustainable products in an effective way. The objective of this study is to investigate the thermal and energy performances of a contemporary conceptual form for residential villa in hot-arid climate. By exploring different passive strategies including natural ventilation and daylighting, in addition to evaporative cooling, this paper is verifying the architectural decisions of recalling the court-yard, and the introduction of sloped-roof attic concepts to the modern house design in Riyadh.

**Approach and Methodology**

Riyadh is a good example for hot-arid climate regions with special social concern regarding the privacy. To test the passive strategies, a residential villa model in Riyadh is developed as the case study. Using the Saudi energy code and ASHRAE-62.2, the base line is compliant with related standards and codes. Then, energy consumption of the model was analysed using DesignBuilder software. This software tool is considered as the visual version of famous Energy-Plus. The software analyses the building performance based on historic-hourly weather data while using built-in libraries for the different building systems. Three main passive strategies were investigated in the added semi-interior spaces: natural ventilation, evaporative cooling and solar space heating. Integration between these strategies is attempted by investigating their impact in terms of sources efficiency, environment consciousness and social effectiveness. Eventually the, architectural concept is verified by the comparing, analysing the results from both base case and the sustainable model. Fig. 1 shows the flowchart of the study methodology.

![Methodology flow-chart](image)
Base Case Development and Verification

**Base Case Development**

The modeled base case study is simulated in an hourly-based weather data for Riyadh. The base case represents a common dwelling unit in Riyadh, as villas represent more than 52% of the residential buildings (HCDA, 2015). The physical and thermal characteristics are defined in Table 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Component Description / Characteristics</th>
<th>Component</th>
<th>Description / Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Riyadh, Saudi Arabia (24.7 N lat, 46.7 E lon, 620 m above the sea)</td>
<td></td>
<td>Occupancy</td>
<td>7 People</td>
</tr>
<tr>
<td>Weather</td>
<td>Riyadh Weather Data, 2015</td>
<td></td>
<td>Lighting Power</td>
<td>6 W/m²</td>
</tr>
<tr>
<td>Orientation</td>
<td>Front Entrance Facing East</td>
<td></td>
<td>HVAC System</td>
<td>Residential System (Heat-Pump, CV-DX)</td>
</tr>
<tr>
<td>Floor-to-Floor</td>
<td>3.5 m</td>
<td></td>
<td>Heating COP</td>
<td>3</td>
</tr>
<tr>
<td>Height</td>
<td>643 m²</td>
<td></td>
<td>Cooling COP</td>
<td>3</td>
</tr>
<tr>
<td>Floor Area</td>
<td>12%</td>
<td></td>
<td>4 Rooftop Units</td>
<td></td>
</tr>
<tr>
<td>WWR</td>
<td>40 mm Concrete Tiles + 20 mm Cement + 70 mm Concrete, expanded + 200 mm Concrete, cast U-Value: 0.19 W/m² K</td>
<td>Glazing</td>
<td>Double, Low-e, Clear (330mm), U-Value: 2.44 W/m² K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 mm Concrete, precast + 90 mm XPS Extruded Polystyrene + 150 mm Concrete, precast + 13 mm Gypsum Plasterboard U-Value: 0.35 W/m² K</td>
<td>Exterior Walls</td>
<td>100 mm Concrete, precast + 90 mm XPS Extruded Polystyrene + 150 mm Concrete, precast + 13 mm Gypsum Plasterboard U-Value: 0.35 W/m² K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 mm Concrete, precast + 90 mm XPS Extruded Polystyrene + 150 mm Concrete, precast + 13 mm Gypsum Plasterboard U-Value: 0.35 W/m² K</td>
<td></td>
<td></td>
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</tbody>
</table>

The architectural concept is simply a reintroduction of the historic courtyard, with a modern ventilated roof. Courtyard is a unique element in Islamic Architecture. It had been commonly used for the sake of private semi-exterior spaces that will enhance the thermal environment of the house by allowing the air to cross ventilate the house core. The air will ventilate takes out heat from the rooms adjacent to the court as shown in Fig. 2. But, this strategy is only valid when the temperatures inside the rooms adjacent to the court are having almost the same or more than the court. Then, air speed and humidifying the air using fountains in the court will make the positive difference needed. However, creating court today within actively cooled adjacent spaces will have a negative impact. That is because the interior spaces temperatures are way less than the temperature outside. Inducing heat flow to the house adds more loads to the HVAC system. (Al-Hemiddi, N. A., & Al-Saud, K. A., 2001)

![Figure 2. The concept of ventilated court (Al-Hemiddi, N. A., & Al-Saud, K. A., 2001)](image_url)

On the other hand, the concept of this house is to introduce a semi exterior area along the core of the building as shown in Fig. 3 (a). Creating a private shaded area for swimming pool, transparent facades that link the two masses with each other and allow the use of indirect natural lighting with minimum heat gain through the glazing. Moreover, the tilted roof will provide attic space that potentially been used as heat storage during winter, and ventilated roof during summer. Fig. 3(b) shows the plans and 3D view of the base case.
Figure 3. (a) Concept development. (b) 3D view and floor plans

**Base Case Energy Simulation**

Using DesignBuilder software, building energy performance simulation was conducted. Results were excluding the hot-water calculation. The calculation results for the energy use simulation at the building level were based on the typical year weather data for Riyadh. The energy use within the house was simulated for a whole year. According to the simulation results, the annual energy intensity (EI) for the house was 117.87 kWh/m² per year, which implies emissions of approximately 49.5 tons of CO₂ per year. Fig. 4 (a), shows the breakdown of the energy consumed by the building. Cooling and heating purposes consume more than 80% of the total. While (b) shows the annual profile of the major energy consumptions. The lighting consumption increases during the summer vacation with the occupancy schedule.

Sustainable Model

In the sustainable model, six passive strategies, listed in Table 2, are implemented and evaluated to approach sustainability. The model is then verified in terms of energy consumption and environmental performance.
Table 2. The passive strategies

<table>
<thead>
<tr>
<th>Corresponding System Strategy</th>
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</thead>
<tbody>
<tr>
<td>ST-1: Envelope</td>
</tr>
<tr>
<td>ST1-1: Glazed-shell Atrium</td>
</tr>
<tr>
<td>ST1-2: Roof Attic</td>
</tr>
<tr>
<td>ST-2: HVAC</td>
</tr>
<tr>
<td>ST2-1: Evaporative Cooling</td>
</tr>
<tr>
<td>ST2-2: Natural Ventilation</td>
</tr>
<tr>
<td>ST2-3: Solar Space Heating</td>
</tr>
<tr>
<td>ST-3: Lighting System</td>
</tr>
<tr>
<td>ST3-1: Natural Lighting</td>
</tr>
</tbody>
</table>

The first group of strategies is ST1: Envelope. This group isn’t directly affecting the energy consumption. However, these strategies are mainly to control the condition within these specific spaces as it will definitely enhance the application, evaluation, and the maintenance of the other strategies. Fig. 5 shows the envelope strategies implemented.

![Figure 5. Envelope-group strategies](image)

The second group, ST2: HVAC, assists the HVAC system performance. Passively cooling and heating the adjacent spaces can reduce the load on that space while using low-or-no energy strategy. These strategies are natural ventilation, evaporative cooling, solar space heating. Applying these strategies in the unoccupied and semi-exterior spaces minimizes the concerns related to ventilation and the air quality.

Eventually, the third group consists of one strategy, ST3-1: Natural lighting. The utilization of natural lighting is already considered in the concept development. However, in the sustainable model, utilization of natural light is considered with less heat gain. As it’s indirectly introduced to atrium, then, the adjacent spaces.

(ST1-1): Glazed-shelled Atrium

The idea of the Atrium is to make a semi interior space that uses less or zero energy to have higher temperature during winter, and less temperature during summer, within a naturally lighted and private space. Conceptually, this space is ventilated, shaded and private to maximize its utilization and introduce the natural light with less heat. However, the indoor temperature was still high and fully shading wasn’t assured in the base case. Therefore, the idea of closing the atrium with semitransparent shell emerged. The shell assures the control and monitor the air properties inside the space while transparency was provided where needed to maximize the utilization of indirect natural light. Atrium desired temperature can be 30° C as the swimming pool won’t be desired in cooler temperatures. Moreover, the cooling load due to glazed façade will consume more energy to be fully out of the space.
However, glazing welcomes the direct sun light during winter to heat the space to be higher than the outside dry bulb temperature. Glazing in the western and eastern façades reach a percentage of 70% and is shaded vertically by high reflective blinds with evaporative cooling schedule.

(ST1-2): Roof Attics

Attic is defined earlier as an extra space between the occupied spaces and the real roof of the building. It could be occupied in some cases or used to store, or as playing area. However, it’s not quite practiced in Saudi Arabia and can result in unique shape and enhance the architectural image. In the sustainable house model, Attics can be used in the two masses to reduce the heat gain through the roof. For the function, they are simulated as unoccupied space with the same temperature profile as the Atrium has. The slope of the roof is 22.5°C, which is close to the best fixed angle for PV installation for Riyadh. However, the structure of the attic will be lighter, and the material used have less U-values than the building itself (0.8 W/m²K).

(ST2-1): Evaporative Cooling

In hot & arid climates, hot air is capable to carry good amount of moisture which lowers its temperature in an adiabatic process as shown in Fig. 6. The air can be forced by natural forces or mechanical system (fan). Air has to pass through or in touch with wet medium (pad) before being introduced to the space. Indirect evaporative cooling can be defined as the utilization of evaporative cooling system to reduce the heat gain of the space instead of directly get rid of the heat. This includes introducing the system to the adjacent unoccupied spaces.

![Figure 6. Evaporative Cooling Process on the psychrometric chart (Hootman, T., 2013)](image)

DesignBuilder software allows to freely form the unit needed through many HVAC templates. Fig. 7 (a) shows the specifications of the wet pad used while (b) shows the composition of the evaporative cooling unit.

![Figure 7. (a)Wet pad specifications. (b)Evaporative cooler unit. (DesignBuilder Help, 2011)](image)
The utilization of the system showed promising results. However, the system consumes considerable amount of water. Thus, the system will stop when the outside dry-bulb goes less than 30°C. Fig. 8 shows the fluctuation of air temperature in the central atrium with the use of evaporative cooling system during day time in June. The temperatures shown are the outside temperature, indoor air temperature, radiant temperature and the operative or comfort temperature, which is the average of the indoor air and radiant temperatures. The system starts working by 7:00 am, increasing the humidity to around 60% and dropping the temperature to around 27°C.

![Temperature graph](image)

**Figure 8. Day temperature-humidity profile for the atrium during June**

*(ST2-2): Natural Ventilation*

Natural ventilation can be defined as the use of outdoor area directly through an operable window or operated hole to both ventilate and cool a specific space (Autodesk Sustainability, 2018). However, in hot climates, the use is very limited in time as the comfortable temperature and humidity met rarely by the outdoor condition during the year.

Thus, to achieve the desired temperature for the space, natural ventilation is only used when it allows the space temperature to be around 30°C. This includes a full day cycle during February, March and November, and night cycle during summer (May-October). Fig.9 shows how air temperature of the central atrium follows the outside dry bulb during the 15th March.
Solar space heating can be defined as the effect of heating up a space by solar radiation (Doerr, T., 2012). This effect can be applied during winter. Specially for the sloped roof of southern mass and the atrium, closing the space (no ventilation or evaporative cooling) will let the solar radiation to heat up the space close to the desired temperature. The space will maintain the heat as storage during night, allowing the interior HVAC system to work with less heat losses through the roof and atrium. Fig.10 shows how the air temperature of the central attic follows the radiant temperature during the first day of January.

By implementing the passive strategies to lower the temperature inside the atrium to 30°C, natural light is now welcomed to the spaces with less heat. Testing the real impact of natural light utilization is done by the implementing dimmers control in the desired main spaces. Fig.11 shows the linear control mechanism. The architectural plans allowed the common spaces (living) to be exposed to the view and natural light introduced by the atrium. Linear light control is implemented to estimate the reduction in energy consumption due to daylight utilization. Fig.12 shows the impact of daylight utilization on the hourly lighting power used between 06:00 AM and 13:00 PM.
Figure 11. Linear Control (DesignBuilder.co.uk, 2018)

Figure 12. Daylight Introduction Impact on lighting power density

**Architectural Concept Verification**

By simulating the energy use of the sustainable model, the impact of the strategies combined is examined. And the feasibility of the architectural concept is proven by the reductions caused by the use of low or no energy strategies to assist the building cooling, heating and lighting system. Fig. 13 shows the average temperature profile of the central atrium zone. Through the whole year, the average is kept below 30°C.

Figure 13. Atrium annual temperature profile
Fig. 14 shows the energy annual profiles for both models. Great reduction is achieved during the summer. Peak consumption decreased by more than 50%, recorded in July. This can be added to the social impact of increasing the use of semi-exterior spaces while satisfying the privacy concerns by the semi-transparent shell of the court.

Conclusion

The main objectives of this project were indicated at the introductory section, as follows:
1. Test the impact of the usage of evaporative cooling, natural ventilation and solar space heating on hot-dry climate, through the introduction of the courtyard and ventilated roof.
2. Describe further integration of the passive techniques with the introduction of natural lighting.

Thus, the house model was initiated and described as per the latest Saudi construction requirement in terms of envelope and structure system specification. Also, the house was designed to have energy efficient lighting system as a design decision. Energy consumption of the base case house was simulated in Riyadh climate. The results showed an energy intensity of 117.87 kWh/m² per year.

To approach sustainability in a unique way, integration between an addition of architectural features (semi-glazed shell atrium and two roof attics) to the base case house and the usage a low or no energy strategies were implemented. Evaporative cooling, natural ventilation, solar space heating added to the natural light integration are the main passive strategies tested. The results of implementing and scheduling these strategies in the added adjacent-unoccupied spaces were as follows:
1. Evaporative cooling the adjacent unoccupied spaces (atrium-roof attics) during the daytime and naturally ventilate them during night decreased the energy used for cooling during summer by 35.6%
2. Full-day cycle of natural ventilation on these spaces has reduced the energy use for HVAC by in February and November by almost 43%.
3. Solar space heating utilization for two months has reduced the heating energy by 43%.
4. By introducing linear lighting control in the main spaces adjacent to the court, 49% of energy utilized was saved by the introduction of natural light.

These impacts were combined to have a total reduction of 38.3 % annually compared to the base case house.
References


Natural Ventilation. Autodesk Sustainability Workshop.


Evaluating how Ireland has improved Building Regulations Compliance and Energy Efficiency

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Abstract: This paper reports a study of evaluating the revised Building Control System in Ireland to establish if they have improved Building Regulations compliance and energy efficiency in the construction of new buildings. The new system of accountability ensures how all involved in the design and construction process are responsible for compliance in a comprehensive mandatory certification procedure, ensuring the design team, building contractor and subcontractors all certify compliance that the work is compliant with the Building Regulations. The research is practice based among building regulation certifiers in Ireland to investigate the level of Building Regulations compliance since 2014 with the consequential improvements in energy efficiency. Research in Part L compliance has shown to be less than satisfactory, but since the new system was introduced, there is a high degree of accountability from both designers and constructors in the construction process. The findings suggest that the level of Building Regulations compliance have greatly improved, as certifiers are at risk of litigation from certification misstatement. Energy efficiency has improved in the construction of new buildings as Part L compliance is certified at design stage by the design certifier, construction is certified by the building contractor, sub-contractors and ancillary certifiers, and full compliance is certified by an assigned certifier who is responsible for overall compliance. The revised system provides responsibility on each certifier to detect and remedy non-compliant issues and the paper suggests a framework to assist certifiers in determining the risks to reduce the risk of litigation.

Keywords: Building Regulations, Building Control, Compliance, Energy Efficiency.

Introduction and background

The Building Control regulatory system in Ireland changed with the enactment of the Building Control (Amendment) Regulations (BC(A)R) 2014 after thousands of dwellings were found to have structural defects caused by pyrite and high-rise buildings were found to have inadequate fire safety measures. Non-compliance with the Building Regulations were discovered in a Building Control system that permitted certificates of “substantial compliance” with the Building Regulations during construction and at completion of buildings or works. In some cases, building regulation certifiers’ certified substantial compliance based on a visual inspection at the end of a project. Consequently, to improve compliance the Irish government enacted the Building Control (Amendment) Regulations 2014 to ensure buildings had to be designed, constructed and certified in accordance with the Building Regulations before, during and after construction.

BC(A)R 2014 introduced three new certifier roles with the “Design Certifier” having responsibility for overall design compliance, the “Ancillary Certifier” having responsibility for design or construction compliance and the “Assigned Certifier” being responsible for overall Building Regulations compliance based on certificates produced to him. The Design Certifier and Assigned Certifier must be a registered architect, registered building surveyor or chartered engineer and the Ancillary Certifiers are selected by the Assigned Certifier to certify compliance in the Inspection plan. Building Control in Ireland was transformed from a system
of substantial compliance to a stringent accountable system design and construction compliance.

**Problem Identification and basic principle**

The Building Control (Amendment) Regulations 2014 were introduced to formulate an improved system of Building Control and Building Regulations compliance in both design and construction, but the mandatory wording on the certificates of compliance puts the building regulation certifier at risk of litigation from certificate misrepresentation if the building or works are subsequently found to be non-compliant with Building Regulations.

Research by Keaveney and Compton (2016), indicated that 85% of respondents agreed the new regulations introduced in Ireland would improve the standards in construction from better supervision and inspection and having greater responsibility and accountability from all involved in the construction process. However, the perceived improvement in compliance may be because certifiers’ have increased and improved site supervision inspections due to the risk of litigation from compliance certification.

As a rule, there are two basic defect types, which are defects that occur in design or defects that occur during construction. Under BC(A)R 2014, the design certifier or one of the ancillary design certifiers may be responsible for design defects, but defects that occur during construction may be the responsibility of the building contractor, subcontractor or ancillary certifier that certified the work. The law of a construction contract is largely based on contract where the subcontractor indemnifies the main contractor against their work. However, this procedure becomes complicated under BCAR 2014, where it is possible that the contractor, subcontractor and certifier can be held responsible or partly responsible for a defect, as the main contractor and subcontractor can allege that the ancillary certifier should have noticed the defect and is partly responsible. The certifier may have vicarious liability for consultants under his control and can be found responsible for their actions if they are negligent. “In many instances, architects are legally responsible for the conduct and performance of their consultants, just as they are for employees” (Demkin, 2008 p.357). The Assigned Certifier should therefore select experienced high-quality consultants to reduce risk of liability.

Certifiers’ professional indemnity insurance may be impacted from litigation claims if buildings or works are subsequently found to be non-compliant with the Building Regulations. The president of the RIAI, John Graby, believes that “Architects must be able to get professional indemnity insurance, and if the new duties imposed amount to a guarantee, then we have a problem” (Lee, 2013, p.3). The regulations are therefore a threat to certifiers’ professional indemnity insurance, as completion certificates must state that both design and construction is compliant with the Building Regulations, but this can be amount to certification misrepresentation when minor defects remain on completion or if latent defects subsequently occur.

The amount of certifiers’ time has increased in the certification process and this cost has impacted on the overall cost of construction. Professional fees increased after the introduction of BC(A)R 2014, but fees were greater in small extensions and one-off houses as a ratio to overall cost than large projects. “It has been suggested that the additional hours required to fulfil the roles and services of DC\(^1\) and AC\(^2\) under BCAR SI.9, based on the construction of a one-off house with a completion programme of 40 weeks, would be in the

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\(^1\) Design Certifier
\(^2\) Assigned Certifier
region of 155.5 hours over and above normal professional scope of service (Ramsey, 2014 p.14). Consequently, to reduce the cost of professional fees associated with building a dwelling or dwelling extension, the Irish government enacted the Building Control (Amendment) Regulations (BC(A)R) 2015 that allowed building owners to opt out of the mandatory professional design and certification procedure in the construction of single unit dwellings or extensions to dwellings.

Most building contractors’ insurance are “all risk” in nature, but it is not a warranty or liability insurance. Exclusions commonly found in building contractor risk policies are wear and tear, deterioration, depreciation, loss, damage, defect, design error, design omission or remedying poor workmanship (Wedge, 2015). Consequently, there should be a mandatory requirement in BC(A)R 2014 requiring building contractors to take out latent defects insurance before the commencement of a project.

Design certifiers must be consciously aware of possible design defects when certifying building regulation compliance. In research conducted by Chong and Low (2006), they found in a 74 unit building survey, that the three most important design-related failures were moisture, weather impact and impacts from occupants. Design failures can be problematic for certifiers’ as the mandatory wording in the certificate of completion by the assigned certifier is as follows: “I now confirm........that all have exercised reasonable skill, care and diligence in certifying their work in the ancillary certificates scheduled” (DECLG, 2014). This wording on the certificates of completion by certifiers will give the legal profession armoury when taking a civil action against a certifier if the Building Regulations are non-compliant. The assigned certifier must certify that others involved in the project have exercised reasonable skill and care and if that fact is untrue, it leaves the assigned certifier in a precarious position when certifying full compliance.

Building Regulations Non-Compliance

There are many areas of construction where non-compliance can be found on a building site, but a study by Baiche, Walliman and Ogden (2006), list the main reasons and causes of building regulation non-compliance. They suggest that poor workmanship, ignorance of details or regulations, poor management, use of incorrect or non-certified materials, conflict or confusion between trades, pressure to complete work, changes to approved designs, unfamiliarity with design, complicated labour intensive details and lack of detailed calculations, but they argue that site operatives and site management have the responsibility for non-compliance and certifiers should not be enforcers but instead should be certifiers.

Compliance with the Fire Safety Regulations are reliant on the building contractor’s ability and reliability to carry out the work responsibly and professionally with site visits from the certifier to ensure compliance, but the certifier can’t be expected to be on site for all aspects of fire safety construction. In the UK, there is a perception that if the building is building regulation compliant, then it has to meet fire safety legislation, but the building may not be safe for occupants as the fire risk assessor “may not justify imposing insulation on all fire doors, nor restricting the amount of smoke production” (Jackman, 2006 p.58) as he cannot be responsible for the whole scenario, but is responsible only for the area of fire safety he is certifying. However, the situation in Ireland differs, as BC(A)R 2014 ensures the Design Certifier is responsible for fire safety design, while the building contractor and Ancillary Certifiers are responsible for fire safety construction.

Fire safety measures can be the most important element of Building Regulations compliance, as non-compliant fire safety construction in buildings can cause loss of life. Fire
stopping underlines the broad knowledge required by certifiers to be competent of identifying areas where fire safety measures are substandard. Research by Stewart (2009) indicate how subcontractors can interfere with fire stopping measures of fire compartmentation compliance, that include the plastering subcontractor, carpentry subcontractor, electrical subcontractor, mechanical subcontractor, ductwork subcontractor, brickwork subcontractor, fire door subcontractor and fire protection subcontractor. However, fire stopping measures can be compromised by a change of specifications not being communicated to all subcontractors or inexperienced installers. Therefore, site inspection certifiers must be vigilant to examine the work of both the main building contractor and the various subcontractors on site who have responsibility for installing or interfering with fire protection products.

To achieve Site Preparation and Resistance to Moisture Building Regulations compliance, certifiers must be aware of dangerous substances and the necessity to protect buildings from radon gas. Radon gas is a continuing health problem in Ireland, as “it amounts to 150 – 200 cancer deaths in Ireland per year” (Long and Fenton, 2011, p.96). Radon membranes are commonly used in buildings to protect the building occupants from radon gas entering from the ground, but can also protect from moisture entering through the floor. In a study between 1989 and 1992, radon gas was found in “more than 10% of houses have radon levels greater than 200 Bq/m³” (Radiological Protection Institute of Ireland, 2002, p.1) which are dangerously high levels of radon. One third of Ireland is deemed to be a high radon area, where a house located in a high radon area can have seven times the risk of a house in a low risk area (Fennell, et al., 2002). To make buildings compliant with radon membrane, it is necessary to pay great attention to detailing and workmanship. The moisture and air seal must bridge cavities in walls and make a cavity tray. Therefore, to ensure building regulation compliance, a radon specialist subcontractor should install the radon membrane to ensure gas tight seals around pipes and junctions in accordance to correct specifications and installation methods.

The Radiological Protection Institute of Ireland (RPII) radon map of Ireland is divided into 10km x 10km squares to portray an estimated level of radon gas in any area, but the levels of gas are only an estimated level and can vary greatly from the levels indicated on the RPII map. In a radon test of a dwelling in Castleisland, Co Kerry in 2003, it was found to have the highest level ever recorded radon gas measurement in a dwelling in Ireland at 49,000 Bq m⁻³, even though it is evident that it was situated on the RPII map at a low level radon area of between 10% - 20% of dwellings above 200Bq m⁻³ (Organo and Murphy, 2007). This shows how extremely high levels of radon gas can be found in a dwelling located a relatively low RPII radon gas area, illustrating how important how important it is for certifiers to ensure radon membranes are correctly installed in all areas.

In certifying Building Regulations compliance with Materials and Workmanship, the design certificate and certificate of completion should include compliance with the Construction Products Regulations (CPR), where all construction products must include the CE mark and Declaration of Performance (DOP) from the manufacturer. A certifier must ensure products bear the CE mark and must be used for the way it is intended. The Code of Practice suggests records should be kept for a minimum period of six years, the building regulations do not set a time limit and it is therefore advisable that certifiers should retain DOP, installation records and ancillary certificates for 10 years after completion. BC(A)R 2014 imposes a greater responsibility on design certifier where “fitness for purpose” is a significantly higher bar than “due skill and care” (Hegarty, 2015). Therefore, the situation in
Ireland it is quite different to the UK where market surveillance is monitored by the local trading standards agencies as opposed to the building control authorities in Ireland and architects in the UK have no responsibilities beyond specification leaving the building contractor solely responsible for compliance on site, while BC(A)R 2014 in Ireland ensures the Design Certifier is responsible for drafting the specifications and the Ancillary Certifiers are responsible for the implementation of the specifications on site.

The requirement to install ventilation in a building is a requirement under Part F Technical Guidance Document (TGD), but the common use of natural ventilation grilles can have a negative effect on energy efficiency. It is common for developers of housing developments, to install insulation in the external walls to satisfy the requirements of Part L TGD, while knocking out holes in the walls for vents to satisfy Part F TGD. They both satisfy the building regulations, but breaking out holes in the wall for ventilation is counter-productive in the conservation of fuel and energy. Developers will continue to construct large housing developments with natural ventilation wall vents, as mechanical ventilation can be regarded as an unnecessary expense. Mandatory legislation is necessary for mechanical ventilation installation to become standard practice, as mechanical ventilation in airtight buildings can have a great impact on energy efficiency. However, a study by Kinnane, Sinnott and Turner (2016) found that many airtight homes do not provide the air required changes to be building regulation compliant and purpose provided ventilation is necessary. Therefore, as airtight buildings are increasingly being designed and constructed, it is essential for certifiers that buildings are checked before completion to ensure ventilation is provided with the minimum air change requirements.

Compliance with Drainage and Wastewater Disposal should be carried out by competent certifiers with competence in wastewater design and installation. Septic tank systems have traditionally been used as a method of on-site wastewater treatment in rural areas of Europe, but many septic tanks in Ireland are leaking, not being maintained, polluting water sources where they are “designed to overflow between one and two metres below ground surface: consequently the topsoil does not feature in the equation” (Robins, 1998, p.3). It is widely accepted that “wastewater treatment plants and rural septics tanks continues to be the main source of water pollution in Ireland” (Callanan and Keogan, 2003 , p.220) and they are a “potential source of water pollution in headwater catchments” (Withers, et al., 2014, p.123). Consequently, many private waste water systems installed in one-off houses throughout Ireland are in poor condition, with inadequate supervision of the installation and maintenance of wastewater treatment systems. Therefore, to ensure compliance, certifiers’ should insist before installation, that a maintenance agreement is in place between the building owner and the manufacturer to ensure regular maintenance is maintained.

With building control systems in place in the UK, it may be considered surprising “that 80% of the estimated 1.5 million private sewage systems (PPS) in the UK are working inefficiently” (Brownlie, et al., 2015, p.131). Ireland also, have many wastewater treatment systems working inefficiently, as during a review by the Environmental Protection Agency (2015), between the 1st of June, 2013 to the 30th of June 2014, it was found that of 987 inspections, only 52% passed the inspection examination. In research conducted by Naughton and Hynds (2014), they found that only 32.6% of 722 respondents said that their wastewater treatment systems were de-sludged at least every two years. These statistics appear to indicate that many of the problems with septic tank pollution may come from unmaintained sewerage systems and show they may be working inefficiently in both the UK and Ireland.
Airtight testing in a building is a requirement of the building regulations and the required air change per hour is expected to improve with Part L TGD by 2020. In research carried out by Sinnott (2016), the greatest single leakage path was found to be in boxed-out waste and soil pipes from ground floor level to the unheated attic. Many of the existing passive wall vents were partially or fully obstructed, and many painted over several times caused rooms to be under ventilated. Consequently, with further improvements expected in Part L of the Building Regulations by 2020 and the construction of energy efficient buildings, design certifiers and ancillary certifiers will require a high degree of skill and knowledge to establish the causes associated with air tightness failure to certify passive houses and energy efficient buildings.

Thermal imaging can provide an indication of thermal bridging inefficiencies to highlight compliance issues. According to Colley (2012), an unpublished report commissioned by the SEAI in 2004, found a representative sample of 52 houses constructed between 1997 and 2002, had only 5% compliance of Part L after thermal imaging tests. However, according to Robinson (2016) when further testing was carried out on the same houses in Parts L, F and J, none of the 52 houses were fully compliant with building regulations. This outlines the stark reality that Ireland have a very small proportion of houses with full building regulations compliance. Before the introduction of BC(A)R 2014, the average home in Ireland is rated as a “D2” with only 0.5% being “A” rated (Curtis, Devitt and Whelan, 2014).

The government of Ireland enacted Part M TGD 2000 providing legislation to facilitate access and use for people with disabilities relating to dwellings, buildings other than dwellings, sanitary conveniences and audience or spectator facilities. Further legislation introduced in Part M TGD 2010, applied to both new and existing buildings. There are different regimes adopted for access and use of disabled persons throughout the world and a study by Prideaux and Roulstone (2009) found that Ireland, Malta and the UK took moderate reasonable adjustments to allow disability access in both old and new buildings. Therefore, while the access and use for people with disabilities were relatively straightforward relating to new buildings, extensions and modifications to existing buildings were not as straightforward.

The DHPCLG (2010) determines how Part M related to existing dwellings other than dwellings, to assist building designers in determining if Part M related to existing building extensions, historic buildings, material change of use, material alteration and to determine if it was practical to modify or provide an approach and access to comply with Part M. This shows how difficult it can be for certifiers to ensure building regulation compliance in existing buildings. Therefore, the access and use building regulations can be subject to interpretation regarding existing buildings as building designers often submit proposals to building control in disability access certificate applications for dispensation or relaxation of Part M TGD.

Research Methodology

The research involved the gathering and analysis of secondary data from Building Control Management System (BCMS) comprising of new projects that commenced throughout 31 local authorities in the Republic of Ireland over a six-month period between 1st of November 2017 and the 30th of April 2018. In total, 5,403 projects had commenced during that period, but for analytical purposes, 540 projects were selected at random which represented 10% of the total number. The purpose of this research was to evaluate the number of stakeholders involved in the process acting with dual responsibility to determine if the regulations are compromised to ensure compliance. It will examine the proportion of building owners that are operating as building contractors and the proportion of Design Certifiers that are also
acting as Assigned Certifiers. The Code of Practice for Inspecting and Certifying Buildings and Works recommends that the builder should be competent and on the Construction Industry Register Ireland, but there is no mandatory requirement on building owners to employ a registered building contractor to construct the building or works and some building owners are also acting as building contractors. The professional bodies of Royal Institute of Architects Ireland, Engineers Ireland and the Society of Chartered Surveyors Ireland recommend that the Assigned Certifier should be independently appointed without the additional responsibility of acting as Design Certifier, but this recommendation is not being widely implemented.

The research also involved a case study of the compliance issues studied in 9 projects for both domestic and commercial developments during a six-month period between the 1st of November 2017 and 30th of April 2018 and set out to establish the extent of compliance in accordance with BC(A)R 2014 and BC(A)R 2015.

Table 1. Analysis of BCMS Compliance Documentation required for Domestic and Commercial Developments

<table>
<thead>
<tr>
<th>BCMS Commencement Notice</th>
<th>Building Type</th>
<th>Floor Area</th>
<th>Design Certifier &amp; Assigned Certifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commencement Notice with Compliance Documentation</td>
<td>1. Dwelling with competent builder</td>
<td>912m²</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>2. Restaurant Kitchen with competent builder</td>
<td>692m²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Dwelling Extension with competent builder</td>
<td>105m²</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commencement Notice with Opt-Out Declaration</td>
<td>4. Dwelling with competent builder</td>
<td>253m²</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>5. Dwelling without competent builder</td>
<td>195m²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Dwelling extension with competent builder</td>
<td>93m²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Dwelling extension without competent builder</td>
<td>45m²</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commencement Notice without compliance Documentation</td>
<td>8. Filling Station Improvements with competent builder</td>
<td>854m²</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>9. Domestic Garage without competent builder</td>
<td>62m²</td>
<td></td>
</tr>
</tbody>
</table>

The research involved projects with compliance documentation, without documentation and dwellings and extension to dwellings with the Opt-Out declaration. The research is designed to evaluate the level of compliance found on each project.

Results and discussions

The analysis of the BCMS data and the case study of both domestic and non-domestic developments highlights the anomalies that exist to show compliance. The documentation required to show compliance under BC(A)R 2014 is comprehensive, whereas the building owners of single unit dwellings and extensions to dwellings that opt-out of the statutory requirements under BC(A)R 2015 may achieve compliance without professional services.
First: Building Control Management System Analysis

In analysing 540 projects on Building Control Management System as shown in Figure 1, it was found that 65% of building owners employed a building contractor, whereas 35% of building owners took on the additional responsibility of acting as building contractor. Of the 189 building owners who acted as building contractors, 69% of building owners worked on single dwellings or extensions to dwellings, whereas 31% of the building owners worked on buildings other than single unit dwellings. These results suggest that 35% of building owners have the dual responsibility of acting as building contractors in constructing their own dwellings and buildings other than dwellings. However, when excluding building owners constructing their own dwellings or extensions to dwellings, 11% of building owners acted as building contractors in constructing buildings other than dwellings. It is unlikely that these building owners are competent experienced registered building contractors and this analysis suggests how the non-mandatory requirement to appoint registered building contractors negates the effectiveness of the regulations.

The research found that 250 of the 540 projects were buildings other than dwellings and 22% of those projects the building owner had appointed a Design Certifier and an Assigned Certifier with separate responsibilities, but 78% appointed a Design Certifier with the dual responsibility of Assigned Certifier. An Assigned Certifier with the additional responsibility of Design Certifier may have a degree of difficulty in defending their actions if a case of professional negligence or certificate of misrepresentation is alleged to have occurred when a building or works are subsequently found to be non-compliant with the Building Regulations. However, 73% of single unit dwelling building owners opted out of the statutory certification process and the remaining 27% opted into the statutory certification process. This implies that dwellings may continue to be constructed below the required standard of Building Regulations compliance.

Figure 1. Analysis of 540 BCMS Projects throughout 31 local authorities in Ireland over a six-month period.
Second: Case Study Analysis

The documentation required to show compliance in the BCMS depended on the type of commencement notice that was submitted. In the 9-project case study, the level of compliance found on sites as shown in Figure 2 were graded on the site inspections indicating the amount of construction compliance issues found to be correct on site and the material documentation required to show compliance. In analysing the compliance issues associated with buildings requiring compliance documentation, compliance was found to be correct during site inspections between 75% and 100%, averaging at 95%. This contrasted with projects where building owners opted out of the statutory regulatory system between 34% and 100%, averaging at 73%. Finally, in projects where compliance documentation was not required, compliance was found to be correct between 20% and 84% averaging at 66%.

The level of compliance found in projects with compliance documentation was found to be greater than projects without compliance documentation due to the certifiers’ inspection plan, a competent building contractor and accountable certificates from all involved in the design and construction process. In contrast, building owners who opted out of the statutory process that are building their own dwellings or extensions would not have the knowledge or skills to achieve the required level of compliance. In calculating the level of compliance attained, compliance issues outlined in Table 2 were noted at each site visit.

![Figure 2. Levels of Compliance found to be correct in 9 construction projects during a 6-month period.](image-url)
Table 2. Analysis of Compliance issues found on 9 construction sites in a 6-month period

|------------------------|--------------------------|--------------------------------------------------------|----------------------------------------|-------------------|--------------------------|----------------------|---------------------------------------------|----------------------------------------|--------------------------------------------|---------------------------------------------|----------------------------------|

Figure 3 outlines the amount of inspections that correlate to the time involved in the project. The 912m² dwelling took 22 months to complete had a total of 92 site visits from the Architect, M&E Engineer and the Structural Engineer. The Inspection Plan provided a system of accountability that ensured how all involved in the design or construction process were responsible for their work.

![Figure 3. No. of Inspections required in 6 construction projects required to achieve compliance.](image-url)

In adopting a methodological system of compliance, certifiers’ can ensure compliance is achieved in both design and construction. It is essential that building contractors are competent and the certifiers are also competent to ensure a high level of compliance.
However, certifiers are advised to adopt a methodological framework as outlined in Table 3 to ensure the risk of litigation is minimised.

| Table 3. Methodological Framework for Building Regulation Certifiers to show compliance  |
|----------------------------------|---------------------------------------------------------------|
| 1. Record conversations, instructions and meetings. | |
| 2. Maintain and provide correspondence and certificates | |
| 3. Record action to verbal advice in writing | |
| 4. Ensure all ancillary certificates are in accordance with the Inspection plan | |
| 5. Provide drawings, specifications, calculations and documents to show compliance | |
| 6. Record all inspections with notes and photographs. | |
| 7. Maintain detailed records of Inspection. | |
| 8. Record advice from Building Control Authority and action taken | |
| 9. Record disputes or differences between parties | |
| 10. Record and submit any changes in design to the local authority at completion | |

Conclusions

The research shows Building Regulations compliance and energy efficiency in Ireland have improved in buildings or works requiring compliance documentation due to the design and construction compliance requirements, the increased amount of supervision and inspections, the level of accountability and certification required by all involved in the design and construction process and the risk of litigation from certification misrepresentation. For example, an electrical contractor will certify that he installed the electrical system in compliance with the Building Regulations and the Mechanical & Electrical Engineer who supervised the installation will also certify that the electrical system was installed and commissioned in compliance with the Building Regulations. This system of double check accountability throughout the design and construction process ensures how Building Regulations compliance can be achieved with ancillary certificates from all involved in the design and construction process. The Inspection Plan coordinated by the Assigned Certifier ensures inspections are carried out by the Ancillary Certifiers at the relevant stages during the construction process to ensure compliance. The research highlights how projects with compliance documentation have inspections by competent persons and competent building contractors constructing the building can ensure a high level of compliance and energy efficiency as opposed to building owners who opt-out of the statutory certification process.

References


The Applicability Of Different Kinetic Façade Shading Systems In UAE

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Abstract: The world is rapidly changing and the increased reliance upon technology with the great complexity we face today, was exhilarating and bewildering as well as energy inefficient. However, architectural practice today has evolved and pursued various directions toward accommodating changes and movement in the architectural paradigm using different ways and for different purposes. The technological advancement available nowadays have pushed the use of kinetics in architecture far more than what has been possible previously. kinetic architecture has emerged to provide an optimal performance and adaptive solution to address the various and complex demands related to energy efficiency, user comfort and sustainability. This research focuses on the kinetic façade as an advanced shading technology which has been defined as the movement at the building skin that acts to adapt and respond to the surrounding changes of environmental conditions or varying occupants demands. It also provides different classification of kinetic façade through a review of different application of technologies with deployable responsive skins in buildings. However, the fundamental aim of this research is to provide a better understanding of how applicable is using kinetic shading system in United Arab Emirates. It also investigates the obstacle facing kinetic façade in a hot arid climate and which type is more suitable for the use in UAE. Finally, based on the analysis done in this research, a summary and conclusion has been made elucidating the appropriate application of kinetic façade to be used in UAE.

Keywords: Kinetic Façade, Kinetic Architecture, Classification, Shading system, UAE, Challenges and Limitation

Introduction

Architecture has been challenged with endless influencing factors such as weather, time, information, functions, human need, etc. and it should be flexibly designed with more than one dimension to confront these contingencies of infinite forces. The development of architecture from stability and static to movement and dynamic has created changes in the architectural conception. One of the most predominant advancement in the field of architecture, in which the architecture designed to permit movement of parts of the structure without affecting the structural integrity, is kinetic architecture. Kinetic architecture not a recently discovered concept, however, the burst of advanced technologies enabled kinetic architecture to evolve into a higher state and attack traditional architecture. Regulating sunlight, maximizing space and varying the view are not the only means for kinetic designs, but they are also developed to express new artistic, philosophical, and political ideas. Kinetic architecture primary goal lies in constructing spaces and objects that can adapt, reconfigure, and customize itself physically to meet today’s flexible, dynamic, and constantly varying needs of both users and surrounding conditions, thus an adaptable architecture is formed. The focus in this research is on kinetic architecture where the physical movement is the essential part of the formal nature and fundamental function of the building façade shading system, and thus mechanical property of the system will be considered. (Fouad, 2012) (Elkhayat, 2014)

Kinetic façade or dynamic façade relies on both movement and control upon its building’s surface creating a “living skin” which allows the façade to breathe in response to the environment. The main focus of designing kinetic façade is to reach a better management of energy flow, both from the interior spaces of the building to the outside and from the
exterior environment into the building, with the main objective is the user comfort inside the building and the improvement of building’s performance. The foremost innovation in dynamic control of energy flow (displayed in form of light and heat) is facilitated by new material and most recent inventions in sensing, controlling and actuating system. In addition, kinetic façade is applied to help mitigate the effect of overheating, regulate solar radiation and light reflection through controlling procedure and mechanical movements. (Ron, 2012) (Elkhayat, 2014) (Kolarevic & Parlac, 2015)

Designing kinetic façade system will include structures that consist of sliding, transforming, folding, and expanding parts, with embedded computation as the brain of the system. Embedded computation permits kinetic systems to sense change, by using different means such as cameras and sensors, and respond according to the desired needs. Temperature, light, seismic conditions, and wind loads are all changing variables that the kinetic structures react to by modifying its behaviour, or the ability of building to learn what is the best performance will be with the intelligence use of the computational systems. Until today, the innovation use of computational systems in kinetic façades will offer unattainable high-performance solutions to achieve sustainability. (Velasco, et al., 2015) (Fouad, 2012)

**Kinetic Design Key Elements**

Computation is the brain that regulates the information transferred between the system and controls the desired change and motion for the kinetic environment and without the brain it’s incapable of moving. Occupants and users of an architectural space can have an environment that adapt and change according to the gathered information by means of sensing and computation technologies. Embedded computation can sense any change in the environment and control the response to this change within a time consideration, which allows the response to happen within the desired time. The response in a kinetic facade to any change in the environment goes through a process of: input system that collects the information through information receivers, then it processes and analyse the information, after that a reaction from an output system takes place to a response from an input system, with the desired time for a response to happen and the ability of the system to learn the best performance. (Fouad, 2012)

**Classification of Kinetic Façade and its Application**

Some of the kinetic shading system uses mechanical elements applied externally to the building envelope or in the interior or it can be embedded within the facade. A lot of kinetic façade involves a sort of retractable mechanism in which the shading surface can either contract or expand. In addition, kinetic facade has a large influence on the perception of the building, with the responsive high-tech systems on the façade that utilizes a sensor network that monitors the environment by tracking outdoor and indoor climatic variables, automate control system of operable building elements, and an actuator that provides a movement. (Meagher, 2015)

A comparative analysis of existing responsive building façades exposes different approaches or implementation of technologies in building façade system. There are different classifications done by different authors about the utilization of kinetics in the building façades. However, classification considered in this paper is based on substantial representation of actuating technologies of existing responsive façade system. In the building envelope, there are five different methods of actuating technology which are mechanical technology, pneumatic technology, electromechanical technology, hydraulic technology, and
material-based technology; however, the material-based will not be tackled. The focus in this research is actuating happens because of a response from a control system in a building façade not from a molecular change in the material structure when they are triggered by external forces. An application from an existing responsive façade system will be presented in each classification.

**Mechanical Technology**

Mechanical technology acts as a linear actuator which executes a movement by transforming rotary motion into linear motion. It uses external forces to produce rotation, translation or combined movements in the façade mechanisms. However, the use of this technology in kinetic façades goes through a process before any movement is produced. As illustrated in figure 1 which have the same configuration used in (Matin, et al., 2017), an input is from environmental stimuli or user preferences that move a hand-operated blind using a mechanism of pulleys, cables, and gear system. The movement happens in the façade based on the visual or thermal preferences of the building occupants to overcome the undesirable air-flow, natural light, and dust. (Davecramer, 2016) (Matin, et al., 2017)

*Figure 1: Sensing, actuating and control technologies used in Mechanical, Electro-Mechanical, Hydraulic and Pneumatic technologies (Matin, et al., 2017)*

*Figure 2: Interior and exterior view of the penumbra mechanical system (Kurt, 2014)*

**Penumbra kinetic shading system in 2014**

Penumbra system is one of the recent concept that is comprised of group of vertical shading louvers located external on the facade that uses a manual operated by hand mechanism or computer operated system actuated by two interdependent gear and cog systems, as shown in figure 2. This system converts the configuration of the louvers from vertical to horizontal when the sun reaches an altitude where the vertical louvers becomes
ineffective. It increases sun protection, control the effect of sun glare, and provided a solution for both high afternoon sun and low evening sun conditions. (Kurt, 2014) (Matin, et al., 2017)

**Electro-Mechanical Technology**

Electro-mechanical actuators are powered by a motor that transforms electric energy into mechanical rotation or torque. Subsequently, the rotating motion of the motor is converted into a linear movement. However, in electro-mechanical technology the input source is triggered by a temperature, moisture, light or touch sensors which sends the information to a central-based control system that responds using a mechanism of motor-based or electrical actuator, as shown in figure 1. The significant advantages of using electro-mechanical technology is that it’s a mature and reliable technology, and possesses an inexpensive initial cost, modularized design components, standardization of parts, and centralized monitoring and control. (Davecramer, 2016) (Matin, et al., 2017)

**U.S Pavilion at Montreal Expo. in 1967**

The U.S pavilion, Expo 67 is one of the first ambitious automated climate responsive envelopes done by Buckminster Fuller’s which never worked properly. The interior canvas sunshades were designed to be a soft self-regulated shading system which works based on an automated roller blind. As shown in figure 3, the mechanical actuators of this system involve a complex set of shade cables, 600 conventional motors, and group of fixed rollers and cables, which individually closes and opens the façade’s shutters by wrapping and pulling group of shade cables. These electro-mechanical actuators, for the first time, were incorporated with light sensors to thermally control the structure’s interior environment and then were eventually disabled. In addition, the façade shutters are controlled with a computer program that adjusts their position according to the sun movement. (Matin, et al., 2017)

**Kiefer Technic Showroom in 2007**

The design of the responsive façade of Kiefer Technic showroom was intended to improve the climatic situations internally based on user preferences, outdoor environmental conditions, and the appearance appeals of the façade. As shown in figure 4, the façade has exterior perforated aluminium panels that is controlled centrally by using regional climate data and light sensors, it can also be controlled by human command alternatively. The panels in the façade moves hourly in a vertical translation with a folding joint, this permits a series of a compositional vertical patterns using linear actuators which is actuated using 56 motors. The system is not that much sustainable as it uses a considerable amount of energy. (Matin, et al., 2017) (Moloney, 2011)
**Tessellate System in 2010**

The Hoberman Associates designed a number of kinetic, adaptive shading systems, in collaboration with Buro Happold, an international engineering firm, co-founded the Adaptive Building Initiative (ABI). The ABI has established an adaptive system called Tessellate. Tessellate system, embedded within the glass, is an independent, bordered perforated screen that is composed of stacked panels which overlaps and moves forming a kaleidoscopic pattern. This variable patterning is achieved by shifting the layered patterns relative to each other, using a housed motor integrated in each panel which provides the rotational translation movement of the sheets. However, this overlapping of different pattern plays with the concept of transparency which is used to control solar gain, regulate the natural light level, air flow and ventilation, views, and privacy inside the building. As shown in figure 5, the perforated patterns in tessellate façade system are centrally controlled stainless-steel panels, in which the control system uses light level, temperature, and time of the day sensors to constantly alter the opaqueness of light through using linear actuators. However, each unit operate on a single motor which is regulated by a single computer processor. It can be set to revolve once a minute or a full rotation every hour. (Kolarevic & Parlac, 2015)

**Adaptive Fritting in 2010**

Similar to Tessellate system, Adaptive Fritting produces graphic movable patterns of changeable density, and therefore could be used to control solar heat gain, transparency, and regulate light transmission while permitting an adequate transparency for viewing. As shown in figure 6, Adaptive Fritting, which is within the glass panels, can control the level of transparency and adjusts between opaque and see-through states. In addition, it uses a motorized actuation, embedded between two layers of glass, to produce a real-time dynamic movement, which is achieved through shifting several fritted glass layers to allow the graphic patterns to diverge and align alternately, as shown in figure 7. The shading patterns of Adaptive Fritting are customized and can be repetitive, uniform or non-uniform, etc. This system is simple in terms of design and maintenance, and because of the sculpture quality, the potential application of this system can be in the façade, interior walls, or roofs. (Elkhayat, 2014) (Kolarevic & Parlac, 2015)
Q1 Headquarters in 2010

The external kinetic shading system of Q1 building is made up of 1,280 stainless-steel feather-like motorized louvered shades located on the façade envelope. These “feather” are designed in different shapes, with a constant horizontal overhang combined with a group of vertical twisting fins. As shown in figure 8, the control system tracks the movement of the sun across the sky using data provided by light sensors and programmed weather data, permitting the fins to twist and adjust its position between 0º and 90º (open to closed and in between position). When it is in 0º positions parallel to the façade, it completely blocks direct radiation; while in 90º position perpendicular to the façade, it allows for a full daylight penetration. It also can move independently or in unison as they are individually controlled. (Kolarevic & Parlac, 2015) (Solla, 2010)

Strata Adaptive System

Strata Adaptive System is made up of modular units that contain telescopic fins which can extend to produce a continuous surface or retract into a slender profile. The hexagonal shading system internally occupied the roof of the atrium, as shown in figure 9, which extends to cover the triangulated roof grid. When it is retracted, its profile disappears with the profile structure of the roof. The main function of this system is to act as a sun shading, in which historic solar gain data and an algorithm together with real-time light levels sensors will monitor the shading units. (Elkhayat, 2014) (Kolarevic & Parlac, 2015)

Helio Trace System in 2010

Similar to strata adaptive, Helio trace system is based on the movement of stacked fins that can expand to a nearly closed square surface or retract to slender square shape, as shown in figure 10. It can be positioned on the interior of the roof or externally on the façade. Comparing it with other sliding systems, this system provides a high range of aperture, since each module contains seven layers that are sandwiched together forming a thick unit. It can be programmed to trace the sun path through the course of a day and a year and regulate its square opening as needed. This kinetic shading system maximises views and daylight for
building occupants and significantly lessens solar heat gain by 80%. However, the fins in this system do not need to be totally opaque; it can fritted, perforated, and be made with different types of material. (Kolarevic & Parlac, 2015)

**One Ocean Pavilion in 2012**

The elastic, gills-like kinetic façade system in One Ocean pavilion in Yeosu, South Korea, mimics the fish’s gills movement. The kinetic facade consists of 108 individual vertical lamellas made up of glass fibre reinforced polymers (GFRP) that are flexible and strong creating a vibrant façade pattern to control light conditions and solar exposure. Each lamella is independently controlled and actuated by motors located at the bottom and top edges, to stimulate a compression force which permits a reversible elastic deformation. It makes the lamellas bend asymmetrically forming gill-like openings which permits light inside the building and provide views to the outside, as illustrated in figure 11. The openings of the louvers are in direct relation with its length, the longer the lamellas are the bigger is the illuminated area and the outstanding effect increases. (Barozzi, et al., 2016)

**Garden by the Bay in 2012**

The Garden by the Bay in Singapore, a botanical garden, features a successful example of a large-scale adaptive shading system applied on the exterior of a curved structure. The double glazed curved roof has a retractable external shading system that is made up of triangle-shaped fabric shades, as shown in figure 12. Every shade can be rolled up or extended with respect to solar condition, thus protecting the façade from overheating while allowing light to pass through. In this system, the temperature, humidity, and light are controlled by sensors installed in the interior space of the building and the shades are independently controlled by an advanced self-learning algorithm. When there is an increase in light intensity above the optimum level and reach a certain threshold, motors open two triangular shadings per element. (Barozzi, et al., 2016)

**Hydraulic Technology**

A hydraulic actuator comprises of a fluid motor or a hollow cylinder with a piston implanted in it, which uses a hydraulic power to ease and facilitate a mechanical operation. The output of this mechanical motion is in terms of rotary, oscillatory, or linear motion. The limited acceleration of this approach is the only drawback of this type of actuators. However, in
hydraulic technology the input source is triggered by light, temperature, and photovoltaic/UV sensors which send the information to a centralised control system and Building Management System (BMS) that responds using a mechanism of hydraulic actuators, as shown in figure 1 which have the same configuration used in (Matin, et al., 2017). (Davecramer, 2016)

**Institute Du Monde Arab in 1989**

Jean Nouvel’s Institut du Monde Arabe in Paris has an active shading system embedded between two sheets of glass. The kinetic curtain wall of the building is a glass and steel technological interpretation of the Mashrabiya, traditional Arab lattice screen, as shown in figure 13. It employs an iris mechanism to stimulate 30,000 photosensitive diaphragms which regulates transparency and light levels in a reaction to the sun’s location by narrowing the apertures to reduce exposure to solar energy and dilating to permit daylight to diffuse into the building’s interior. When the apertures or lens is in the closed state, it forms square, circle, and hexagonal shapes. The south façade has 240 high-tech photosensitive motorized square panels; each kinetic panel is composed of one big diaphragm in the middle, enclosed by 16 diaphragms of medium sized, and 55 small diaphragms in the corners, as shown in figure 13c. Moreover, the photovoltaic sensors in this system have been combined with linear hydraulic actuators to manage the centralized structure, in which 10-30 % of daylight can enter inside the building and avoids solar glare. However, the system stopped working because of mechanical problems, mainly due to friction. (Matin, et al., 2017) (Kolarevic & Parlac, 2015)

![Figure 13: (a) Jean Nouvel’s Institut du Monde Arabe in Paris kinetic façade system, (b) Detailed view for the different size and shapes of diaphragms, (c) Kinetic panel while functioning with all different sizes of aperture (Poucke, 2011) (MD, 2017) (Michler, 2010)](image)

**Al-Bahar Towers in 2012**

The external responsive folding shading system of Al Bahar Tower is inspired from the Mashrabiya, which was reinterpreted as triangular umbrellas made up of translucent PTFE fabric. The translucent fabric diffuses direct sunlight and permits view to the surrounding cityscape, and can stand against dust, sand, wind, and UV radiation. The kinetic facade comprises of an approximately 1,049 umbrellas arranged into hexagonal panels that are attached by four hydraulic actuators which are connected to a building management system (BMS). The BMS system interacts individually with each sensor integrated in every hexagonal
panel, and provides the operator a real time light intensity, wind speed, rain levels, folding positions of panels, and errors in a panel. However, there are five diverse operative configurations for the umbrellas controlled by the BMS which tracks the sun movement and location, as shown in figure 14, from completely closed to totally opened by origami-like folding and linear actuation. It is estimated that this type of shading system minimizes solar heat gain and would cut down cooling loads by 25%. (Kolarevic & Parlac, 2015) (Matin, et al., 2017)

**Pneumatic Technology**

Pneumatic actuators are like hydraulic actuators except they generate force when it compresses gas instead of a liquid. It converts energy created by compressing air or vacuum at high pressure into rotary or linear motion. However, in pneumatic technology the input source is triggered by a network of sensors which sends the information to a decentralised control system composed of a network of microcontrollers that responds using a mechanism of pneumatic actuators, as shown in figure 1 which have the same configuration used in (Matin, et al., 2017). The drawback of this system is that the used air compressors are bulky, large, and loud, also it is likely to leak which makes it less efficient than mechanical actuators. (Davecramer, 2016)

**Media TIC Building in 2011**

The Media-TIC building features an active façade that consists of an air cushions made from lightweight Ethylene-Tetra-Fluoro-Ethylene (ETFE) material which provides pneumatic solar shading fixed on the exterior of the façade. The pneumatic cushions, shown in figure 15b, are embedded with sensors that sense light and heat from the sun, and comprise of three ETFE layers with two air chambers in between them, which can be deflated or inflated as required. As shown in figure 15a, the first layer of the cushion coloured blue is transparent, while the second and third have opposite patterns when joined together they form a complementary pattern and would block sun radiation. While if they are separated they permit radiation to pass through the element directly or by reflection. During the afternoon, the air cushions are filled with nitrogen converting the transparent façade into a translucent, thereby blocking sun radiation by 90% and significantly decreasing the building’s heat gain. (Kolarevic & Parlac, 2015) (Matin, et al., 2017)

![Diagram showing the operation of three ETFE layers of the cushion](image1)

**UAE and Adaptive Kinetic Façade**

The hot summer months in UAE reaches a maximum temperature of 47°C, coupled with very high humidity. While milder winter with temperature drop have an average temperature ranging from 17°C to 25°C. The high temperatures of UAE present a key challenge in achieving thermal comfort for building occupants and users as the result of this harsh hot and humid climate. Through understanding the sun chart diagram, the average daylight hours in UAE is
approximately 12 hours, therefore, it is required to shade the south façade and the roof to block solar heat gain, while the north façade is considered comfortable due to lack of direct solar radiation. (MOEW, 2015) (NCM, 2017)

**Challenges Facing Kinetic Façade shading in UAE**

There are multiple of challenges facing the utilization of kinetic façade in UAE, since UAE’s hot arid climate is prone to high heat pressure on summer days and wind in desert areas may cause sand or dust storms. The adaptive shading system whether its external or internal depends on the material, means of actuation, scale, and the maintenance system. However, enclosing a shading system between two layers of sealed glass would eradicates dust or/and sand particles which can penetrate and get into lubricated areas that is used to lessens friction in mechanized assemblies. Therefore, care must be taken to avoid sand or dust from interfering with the kinetic façade because it affects the intricate systems and make them less movable over time. In addition, mechanical shading systems that are positioned external to the building façade are not only exposed to other elements but also to particulate matter which can get into the mechanical system resulting in a greater wear and tear; and therefore, reduce the overall lifespan of the system. It also might increase the possibility of malfunction in the system which would result in extra cost and frequent maintenance than the case of embedded or internal shading system. However, the main challenge in kinetic façade is not the electronics, geometry or the actuation system used but the friction, which is till today remains a problem in approximately all mechanically, motor-based actuation system. That’s why today designers of adaptive system are looking for other means of actuation besides motor-based such as pneumatic, hydraulic or material based actuation. (Kolarevic & Parlac, 2015) (Kuismanen, 2008)

**Limitations of Kinetic Shading Systems**

According to the analysis done on the literature review, the limitation of using a kinetic shading system in UAE depends on several factors other than the challenges discussed above. These limitation factors are (but not limited to) visibility and view, cleaning, noise, space for the system and material. As for the visibility and view, the shading system whether it’s located on the exterior of the façade or on the interior it should not block the view to the outside while it is in an open position to protect the interior from intensive solar radiation. In terms of cleaning, UAE is a country known with a challenge of dust and sand particle. The shading device must not accumulate dust or sand on its surface or the cleaning process of the shading system must not be complicated. However, the kinetic shading system requires sensors, actuation, and control system. The system should be advanced enough for it not to occupy more space from the building to operate and they must not create a noise or distraction for the occupant of the building. Finally, the material of the shading element applied on the exterior of the façade or the interior should be selected according to what can sustainably work within the UAE climate.

**Summary of Adaptability and Applicability of Kinetic Shading Systems in UAE**

The biggest obstacle facing UAE to reach its sustainability goal is the need to reduce energy consumption associated with providing indoor thermal comfort and to respond to constant changing environment. Based on the analysis developed on the literature review about kinetic façade systems, the kinetic facade should actively adapt and interact to the surrounding weather conditions of UAE and manage the energy flow through the building skin to enhance
energy performance, regulate solar radiation, and mitigate the effect of overheating through mechanical movement and controlling techniques.

Matrix has been made in the table 1 above based from the understanding of different kinetic shading system, which was divided to classification according to actuation system used, and their application along with the location of the system on the building façade. Subsequently, each system has been further explored in terms of their challenges and limitation within UAE. After exploiting each system limitation and challenges a resolution of applicability in UAE has been determined. The following is a comprehensive summary of each actuation technology and its possible applicability in UAE:

**Mechanical Technology**

The utilization of mechanical technology involves so many moving parts and uses hand operation as the source of actuation, which might not be the most efficient and applicable shading solution to be used in UAE. Thus, this system is not suitable to be utilized in UAE with the emergence of more advanced systems.

**Electro-Mechanical Technology**

Table 1 presents 9 different applications, some of the applications could be applicable for UAE if some of the challenges and limitation are solved. This first application of electro-mechanical technology in 1967, U.S Pavilion, lacked the advanced technologies that could have led to its ability to operate, thus, making it unsuitable to work in UAE. On the other hand,
Kiefer Technic Showroom and One Ocean Pavilion are applications that provided an attractive dynamic skin but lacks only the ability to view the outside when it is in a close position. This type of electro-mechanical technology could be used in UAE, if the material used as a shading device can allow visibility to the exterior and manages the harsh environment. However, Tessellate and Adaptive Fritting system are simple kinetic shading systems embedded within the glass envelope with variable and customized patterns. Those type of systems are suitable to be used in UAE as it will eliminate sand/dust from penetrating into the mechanized elements and it gives the building an esthetic appearance. While the shading system in Strata Adaptive and Q1 Headquarter building whether it’s on the exterior or interior of the façade are also applicable to be used in UAE. The strata adaptive when it’s not activated, the shading fins are hidden within the structure of the roof or the wall which gives it an advantage in comparison to the other types of electro-mechanical technology. While the Q1 headquarter uses more than 1,600 motors which might be considered as a maintenance nightmare but it’s not because it’s a reliable system due to the advancement of technology today.

Helio Trace system is a shading system that has been already used in UAE, but the fact that it has more than 7 moving layers in each unit makes it more exposed to maintenance issue. In addition, the advantage of using the sunshades in helio trace system is that the process for changing the setting takes only 5 seconds. Finally, the shading system of Garden by the Bay building is applied outside on the roof makes it more vulnerable to sand/dust and frequent maintenance regime to make sure the system works properly. However, with UAE climate this system might face the limitation of cleaning as its going to be difficult to clean the shading material on the roof. Consequently, this system is not the most appropriate type of shading to be used in UAE.

**Hydraulic Technology**

The complex kinetic façade of Institute Du Monde has a problem of friction and it needs to maintain a frequent maintenance of the numerous moving apertures. While Al-Bahar Tower, has been already tested for all the challenges UAE imposes upon a kinetic shading system and had solved the limitation through testing and using the applicable advanced technology needed for UAE’s hot arid climate. Consequently, hydraulic technology could be applicable in UAE since it uses advanced technology needed to reach sustainability goals and through taking Al-Bahar Tower as a paradigm and learning from previous applications. Also, trying as much as possible to embed the system within the skin of the building to prevent the challenge of dust and sand.

**Pneumatic Technology**

Due to the fact the system, in Media TIC building, uses air pressure to fill the cushions on the facade to block solar radiation, it takes 3 minutes to be completely inflated but air might leak making it an undesirable shading solution which will require periodic maintenance and consumes energy. In addition, this system visibility and view from the inside is limited, due to the cushions translucent nature when it prevents heat and solar gain to enter the building. The Pneumatic system requires a space for air compressor and it generate noise, therefore, the limitation and challenges this system faces makes it inapplicable to be used in UAE.

**Conclusion**

The life we live in today is dynamic, thus the spaces we spent our time in should be dynamic and adaptable to our ever-changing needs. Buildings with Kinetic façade are alive, they can follow the nature’s rhythm and can change shape and direction from sunrise to sunset, and
from spring to summer adjusting to the continuous changing weather and environment. Given the increased reliability and effectiveness of dynamic building components and embedded computing as well as reduced cost, it appears inevitable that more buildings will be designed with active components responding to the changing needs of user and environment. kinetic façades have emerged to provide an optimal performance and adaptive solution to address the various and complex demands related to energy efficiency, user comfort and sustainability. Every kinetic façade is a unique system that might be influenced by cultural and regional motifs. The hot arid climate of UAE suffers from high solar exposure and climatic issues, and handling this challenge by introducing active, kinetic façade shading system would decrease the cooling energy consumption. There are multiple applications of kinetic façade using electro-mechanical technology and hydraulic technology that can be implemented in UAE. Therefore, there is a great applicability of this system to change the monotonous, static façades in UAE and improve the energy efficiency and environmental performance of its buildings. The possible success of these buildings with kinetic facade is their ability to learn from the past and take it as a paradigm to be able to confront new challenges in the future.

References
Maximizing the Effectiveness of Solar Energy System by the Integrated Passive Cooling Strategies of Nizwa Eco-House

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Abstract:
This study addressed the impact of the integrated performance of the passive cooling strategies to reduce the cooling load and maximizing the energy productivity of the solar photovoltaic panels in Nizwa eco-house. Selected passive technologies or design features adopted in Nizwa eco house to reduce the temperature of buildings without energy consumption. Different scenarios examined to evaluate the effect of each strategy independently to identify the most significant one and collectively to investigate the integrated performance of these strategies altogether. Consequently, this research aims to examine the performance of the application of selected passive cooling strategies to improve thermal performance and to reduce the energy consumption of residential buildings in hot climate settings at Nizwa in the Sultanate of Oman. Four passive cooling strategies were applied in Nizwa eco-house assessed by computer simulation software (ECOTECT). The assessment procedure based on comparing the cooling load of the proposed baseline scenario, which is without passive cooling with the cooling load of the scenarios after applying the passive technologies. The comparative analysis showed significant reduction in energy consumption was achieved due to applying the integrated approach of the cavity walls, triple glazing, shading canopy and the green roof, consequently the number of solar panels will be reduced. The implementation of these strategies in the Nizwa Eco-house showed a significant effects on the energy balance when the produced energy by the solar panels compared with that consumed by the Eco House. The annual energy produced by the solar system is around 47.3 MWh, while the annual consumed energy by the Eco House is around 44.3 MWh achieving the goal of Zero Energy Balance and exceed this goal by an extra energy of 3 MWh annually.

Keywords: Solar photovoltaic, Cooling load, Energy efficiency, Ecotect.

1. Introduction

The passive cooling strategies involved the techniques and the technologies that employ in the building to reduce the energy consumption of the building. The passive cooling strategies are mainly depending on promoting building's envelope to increase the building performance for saving energy. The building envelope represents the relation between the indoor and outdoor environment. The envelope mainly includes the walls, windows and the roof. The external wall is one of the essential parts of the building envelope. Wall could provide thermal and acoustic comfort and its thermal insulation value is crucial (Pekdogan et al.2017). Florides et al. (2002) concentrated on reduce heat gain from solar radiation is by installing overhang. Direct solar radiation is being prevented to enter window using overhang. The length of overhang affects the cooling load reduction. It could be observed that the longer the overhang, larger is the cooling load reduction. Further conclusions about the effect of windowpanes properties, Yaşar and Kalfa (2012) Identified the most effective factors that influenced the glazing performance. The typical glazing that is applied in the case study is low emissivity glazing as it has well visible transmittance, low U-factor and low solar heat gain coefficient (SHGC).
The building orientation is another factor which affects cooling load. The best direction for a building is the one that would receive a minimum amount of solar radiation in summer and maximum during winter. Meanwhile, Gadi (2010) suggested that by adjusting the shorter side of building against the direction of strongest solar radiation and the longer side of building to block the prevailing wind, the cooling load can be reduced. Applying cross ventilation to a building is one of the traditional methods to provide thermal comfort as well as reducing the cooling load in an indoor environment. However, several limitations such as climate and wind direction prevent this method. Mochida et al. (2006). The roof is a significant part of building that receive/loss high amount of heat gain since it is very susceptible to solar radiation and environmental changes. The problem faced with it is that the installation cost is very high. Applying white paint on a roof has proven to bring in a drop of 6.5℃ on average in the room temperature as stated by Kotak et al. (2014). Evaporative cooling is a process that relied on the effect of water evaporation which acts as natural heat sink.

Another study in hot and arid climate (Riyadh), Venkiteswaran et al. (2017) concluded that transparent elements are the major cause of the high heat gain in school buildings in Riyadh especially during overheated periods of the year. Solar radiation can directly penetrate a building through glazed areas as the weakest element in a building envelope. As a result, blocking the solar radiation before it reaches the opaque and transparent elements of a school building envelope is of great importance. Placing proper over-hang and side-fins shading devices on the windows and/or vegetation can provide shade for the windows. Shading devices can be installed in a school building with reasonable cost and can remarkably improve its thermal performance. According to the literature review, the environmental design strategies aimed to modify the external environment by improving the condition of interior spaces of existing buildings. The external walls, the performance of windows glazing, and the roof insulation are the most active building elements that should be environmentally improved.

In hot climate regions, the majority of the energy consumed by the cooling appliances, therefore, reducing the cooling load in these regions is an essential objective for low-energy consumption approach and subsequently, reduce the electricity bills. The hot climate regions and specifically the Sultanate of Oman as an example of these regions have almost clear sky. The phenomena could encourage using the photovoltaic energy to produce the electricity. There are many factors affect the solar energy production considered some of the major performance-limiting factors include: dust deposition on photovoltaic panels, temperature effects; relative humidity; wind speed/direction shading and panel tilt angle effect [Juliana D’ Angela Mariano et al, 2016], was found that 2.3% daily reduction in energy production due to dust effect. Integration of wind and solar system to produce energy, in order to take benefit from both clean energy techniques and to maximize the renewable energy production, was proposed and considered by [TONGDAN Jin et al, 2015]. Supplying photovoltaic energy to an office building which are one of the most consuming building was studied and investigated [Giovani Almeida Dávi et al. 2017], it was shown that 45% of electricity bill reduction was achieved as such a building normally working during the day hours.

This work reported the implication of the integrated passive cooling strategies to achieve the zero-energy balance of the Nizwa eco-house. The method presented here examines the performance of the application of selected passive cooling strategies to reduce energy consumptions and make the solar photovoltaic system using grid connection technique to
be more efficient in providing the required energy in hot climate settings at Nizwa in the Sultanate of Oman. The main objectives of the Eco House design and construction are to get not only zero energy balance but positive energy balance and to reduce 41 tons of CO$_2$ emission.

2. Methodology

The methodology of these study can be divided into two parts. The first part involved using Ecotect software to simulate the suggested passive cooling strategies owing to investigate the performance of each one. In this part, the study investigated the most effective building elements that reduce the cooling load while maximizing the thermal comfort of the occupants and minimizing the energy consumption for Nizwa Eco-House. A computer simulation carried out to evaluate the thermal performance of the baseline model and to predict the effectiveness levels of various environmental design modifications when applied to the same model. The benefit from ecological design strategies varies with climate, system type, system design and system size. Consequently, this paper intends to investigate the effectiveness levels of some passive solar and energy conservation design strategies that were applied to Nizwa ECO House. Additionally, it aims to test the usefulness of applying selected passive strategies to improve thermal performance and to reduce energy consumption. Each strategy was individually applied to the base case and was simulated by ECOTECT to investigate the influence of each one among the other strategies. Then a comparative evaluation of the overall selected strategies was integrated together in the combined case and evaluated to investigate the role of integration.

The second part was related to the implementation of these strategies in the construction of the Nizwa Eco-House. In this part, the total electricity produced by the solar photovoltaic panels examined at different climate conditions to confirm the positive impact of the passive cooling strategies on the energy balance and on the reduction of the number of required solar panels. The comparison demonstrates the level of improvements achieved by applying these strategies to the base case building design.

3. Simulation

Setting the building zones is the most important step in the methodology of theEcotect simulation and depends on the definition of the spaces of the building as either thermal zone or non-thermal zone, and the term Zone refers here not as architectural space, but it is assumed to be an enclosed space within the building. As such it must be completely enclosed with planar objects forming its floors, walls, ceilings or roofs. There is no restriction on the number of different types of surface, if it is completely enclosed on all sides with enough geometry to allow its volume to be calculated. Determine the location and climate of the city, where the building located. The simulation of Nizwa Eco-House will use Metronome program for getting weather data for the exact location of Nizwa eco-house. Metronome is a meteorological database containing climatological data for solar engineering applications at every position on the globe. The results are stochastically generated typical years from interpolated long-term monthly means. Figure 1. Shows the site information, temperature ranges, radiation, and all zone setting parameters concerning Nizwa ECO House.
3.1 Ecotect parameters settings

3.1.1 Hours of Operation

When a zone is air-conditioned, these define plant ON and OFF times. Unlike other time values, these must be integer hours as A/C loads are calculated hourly. An ON time that occurs after the OFF time simply means the A/C system runs overnight. While not air-conditioned, these represent hours of occupancy, as shown in Table 1.

<table>
<thead>
<tr>
<th>level</th>
<th>zone</th>
<th>Hours of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground floor</td>
<td>Majlis</td>
<td>7 am – 1am</td>
</tr>
<tr>
<td></td>
<td>entrance</td>
<td>7 am – 1am</td>
</tr>
<tr>
<td></td>
<td>Family room</td>
<td>7 am – 1am</td>
</tr>
<tr>
<td></td>
<td>Dining room</td>
<td>7 am – 9pm</td>
</tr>
<tr>
<td></td>
<td>corridor</td>
<td>7 am – 1am</td>
</tr>
<tr>
<td></td>
<td>kitchen</td>
<td>7 am – 1am</td>
</tr>
<tr>
<td></td>
<td>Bath 1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Bath 2</td>
<td>None</td>
</tr>
<tr>
<td>First floor</td>
<td>Master bedroom</td>
<td>8 pm – 9am</td>
</tr>
<tr>
<td></td>
<td>Bath 1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Dressing</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Bedroom 1</td>
<td>8 pm – 9am</td>
</tr>
<tr>
<td></td>
<td>Bath 2</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Bedroom 2</td>
<td>8 pm – 9am</td>
</tr>
<tr>
<td></td>
<td>Bath 3</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Dining room</td>
<td>7 am – 9pm</td>
</tr>
<tr>
<td></td>
<td>corridor</td>
<td>7 am – 1am</td>
</tr>
</tbody>
</table>
3.1.2 HVAC System

Three types of a cooling system proposed in the simulation process: a mixed-mode and full air-conditioning system and none HVAC and described in Table 2. The mixed-mode is a combination of air-conditioning and natural ventilation where the HVAC system shuts down whenever outside conditions are within the defined thermostat range. It should be noted that Ecotect assumes that either the system continues running on supplying mechanical ventilation or the windows are opened. In either case, the air change rate increases as described above. Moreover, Ecotect does not consider the energy used in the ducting of air when it calculates cooling loads - these are both given as space loads not plant loads. While full air conditioning means that cooling systems run as required to maintain the zone air temperature at the comfort level. Windows are assumed never opened, so the only ventilation and infiltration are set in the Air Change Rate settings for the zone. However, NONE means All the windows are doors remain shut with the only ventilation being through the Air Change Rate setting in the Occupancy tab. The occupants completely ignore internal conditions and battle on regardless. The comfort band was set between 25-27 °C. Table 2 illustrates all the HVAC system for each thermal zone at Nizwa eco house.

<table>
<thead>
<tr>
<th>Level</th>
<th>Zone</th>
<th>Type of HVAC System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground floor</td>
<td>Majlis</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>entrance</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>Family room</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>Dining room</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>corridor</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>kitchen</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>Bath 1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Bath 2</td>
<td>None</td>
</tr>
<tr>
<td>First floor</td>
<td>Master bedroom</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>Bath 1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Dressing</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Bedroom 1</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>Bath 2</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Bedroom 2</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>Bath 3</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Dining room</td>
<td>Mixed-Mode System</td>
</tr>
<tr>
<td></td>
<td>corridor</td>
<td>Mixed-Mode System</td>
</tr>
</tbody>
</table>

4. Results and Discussion

4.1 The effect of Shading mass

A high thermal mass structure can absorb and store heat during the day and save it for the night. Thermal mass can also reduce the fluctuations in indoor air temperatures. The capability of the thermal mass, therefore, will cope with the local climate in Nizwa in all seasons. In summer, for example, thermal mass is also a useful strategy to protect the envelope from the harsh environment. The canopy in Nizwa Eco-House, shaded works as thermal mass to prevent the sunlight penetrate the house’s envelope. Figure 2 illustrated the effect of adding the canopy to the Nizwa Eco house. There is a significant reduction of
the total sunlight penetrate annually when the canopy use Figure 2. (a) than when it removed Figure 2(b).

4.2 The effect of external walls insulation

The external walls insulation significantly increased the thermal resistance of the house’s envelope and hence buffer the interior spaces from the outside environment. The external walls in Nizwa eco house constructed using double layer of autoclaved aerated concrete (AAC) with air gap in the middle. U value for this wall was 0.46 w/m².K. Figure 3 demonstrates the (AAC) wall construction details.
The results of monthly cooling load revealed that the AAC block caused decreased from (74115,496 W. h) when the external walls constructed using (0.20 m) thickness of Omani traditional block to (49374,968 W. h) when these walls replaced by AAC block as shown in Figure 4 (a) and (b).

4.3 The effect of the Green Roof

The roof receives a significant amount of solar radiation and is the primary source of heat gain in buildings especially in hot, dry climates. So, by using a high level of insulation it can reduce heat conduction to the interior of the building. Consequently, a green roof installed in the Nizwa Eco-House consisted on a grass with watering system activate at night to evaporate the heat gain and protect it from the intense solar radiation during the day. The results showed that the green roof prompted the saving energy inside the house by decreasing the monthly cooling load from (74115,496 W. h) when the roof constructed using (0.20 m) thickness of traditional concrete roof only to (69532,176 W. h) when installing a layer of soil and grass with the roof as shown in Figure 5 (a) and (b).

4.4 The effect of the triple glazing

Triple-glazing reduces the U-value of glazed areas of the house up to 0.16 w/m².k. Low U-value of transparent elements can reduce the heat gain and loss by conduction and radiation through the glass. All the single-glazed windows in the baseline of the prototype house building replaced with triple-glaze filled by Aragon gas with 0.12m spacing between the three-glazed layers. This modification decreased the monthly cooling load to (68636,624 W. h) as illustrated in Figure 5.
4.5 The effect of integrated approach

It can be concluded from Figure 6 that the external walls insulation provided the most of reduction in cooling load (33%). This significance because the surrounding wall represented the largest area of the house's envelope. Although the canopy has the lowest percentage of reducing the cooling load, it has a significant effect on decreasing the outside temperatures, and the ECOTECT did not take the outdoor area in cooling load calculations. The technology of triple glazing and the agricultural roof almost have a similar impact on thermal building loads (7% and 6% for the triple glazing and green roof respectively). Eventually, All the selected passive solar and energy conservation design strategies, mentioned above, were combined in one case. The main purpose of the combination is to assess the improvements that design strategies can make in the thermal performance if they are applied together to the baseline. The total reduction in cooling load reached (47%) than the baseline model.

![Figure 6. Compare the individual and integrated reduction in cooling load of Nizwa eco house](image)

5. Eco-House solar energy design and implementation

5.1 Energy consumption

One of the most effective techniques in clean energy production, the solar photovoltaic energy production, which is used in this project. In the design and analysis of this system RET Screen software is used. At the beginning of the project and based on the estimated consumed energy of the Eco House considering the effects of the passive features which contribute in energy consumption reduction, the number of solar panels were determined (98 solar Panels). Grid connected Solar system is used in this project, during the day the extra energy produced by the system supplied to the Grid, while during the night, the Grid supply the required energy to the house. The design objective is to achieve a zero-energy balance. The solar system was implemented and tested and under continuous monitoring, regarding energy consumption, energy production and living temperature and humidity comfort. Figure 7(a) shows the annual energy consumption of the Eco House along with the different months of the year. The highest energy consumption is during the summer months, it can reach 4.8 MWh, forming the highest percentage 11% of the total consumed energy. While in winter months is the lowest and it reaches 1.8 MWh, forming the lowest percentage 4% of the total energy consumed as shown in figure 7(b).
5.2 Energy production

The grid connected solar system composed of 98 solar panels, as shown in figure 8, each panel can produce maximum power of 250W peak with 15% efficiency and two inverters of 20Kw and 10Kw synchronized and connected in parallel to supply maximum power of 24Kw peak to the load.

The annual energy produced by the solar system is around 47.3 MWh, while the annual consumed energy by the Eco House is around 44.3 MWh achieving the goal of Zero Energy Balance and exceed this goal by an extra energy of 3 MWh annually. Based on this Energy performance achievement, the first place was awarded to the University of Nizwa’s Eco-House from The Research Council (TRC) of Oman during the national Eco-House competition in 2015. Figure 9 shows the comparison between the energy production and the energy consumption during the year.

It is clear from figure 9 that there is a deficit in Energy Balance during the summer season while there is an advantage and extra energy production during the winter season which is justified and normal in Gulf Region, due to the weather conditions during the year.
5.3 Temperature Effect on the Solar Energy Production

It is very interesting to investigate the temperature effects on the solar energy production, the energy produced by the Eco House solar system was monitored and measured during the hot and cold months. Figure 10 shows the variation of energy generated from the solar system at different temperature, the temperature variation of the remaining months is within the temperature range presented in this figure.

![Figure 11. Temperature effects on Energy production](image)

It is clear from this figure that as the temperature increase beyond 40°C the generated energy starts to decrease effectively although the solar radiation reaches its maximum values at these temperature conditions. A reduction of around 15% in energy production was measured for an increase in temperature from 36°C to 44°C which indicate how the solar panel efficiency is tightly related to the panel temperature.

5.4 Panel Cleanness effect on the Solar Energy Production

As the solar radiation which received by solar panels is maximized, the energy generated from such panels will be maximized, as the number of photons which interact in the solar cell structure to generate electron hole pairs will be increased. In that case it is recommended to keep the panels clean and exposed in a manner to receive maximum solar radiation. To investigate the dust effect and the cleanness of the solar panel on the energy production, two different reading are conducted, one before cleaning the panels and the other after cleaning the panels. It was noticed that the energy production was improved at least by 13% with respect to the dusty and non-cleaned solar panels. These results are shown in figure 12.

![Figure 12. Energy production before and after cleaning](image)
5.5 Emission Analysis

The advantage the clean and renewable energy is to reduce the environmental pollution by reducing CO₂ emission. Based on US Department of Energy, the Green House Gas Emission (GHG) factor is 0.856 ton of CO₂ per 1 MWh electricity production when all type of fuels is considered in the electricity generation process. Based on this fact, the table below shows how much Nizwa’s University Eco-House contributed in the CO₂ reduction; it is around 41 tons annually, which is equivalent to 7.5 cars and light truck not used in the road.

Table 3. Nizwa’s University Eco-House contribution in the CO₂ reduction

<table>
<thead>
<tr>
<th>Base case electricity system</th>
<th>Country Region</th>
<th>Fuel Type</th>
<th>GHG emission factor (tCO₂/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oman</td>
<td>All types</td>
<td>0.856</td>
<td></td>
</tr>
</tbody>
</table>

| GHG emission reduction summary | Project Energy | Net annual GHG emission reduction in (tCO₂) | 48MWh | 41.0 |

| Net annual GHG emission reduction | 41.0 | tCO₂ | is equivalent to | 7.5 Cars & light trucks not used |

When such an energy system is widely and commonly used in place of the conventional energy production, a clean and healthy environment will be established in addition to sustained properties of such clean and renewable energy system.

5.6 Financial Analysis

The technical parameters, the actual cost of the conventional energy production, inflation effects, discount rates and the project life affect the financial viability of the Eco House project. Based on these input data, a cumulative net cash flow using the RET Screen software is given in figure 13 in the yearly base. Knowing that cost of the K W h energy produced was considered as the actual value not the supported value. The cumulative cash flow turns positive at about 14 years and it is the same as Equity Payback period. So that it is worthy to invest in such an eco-friendly project to protect our living environment and to gain money from the sun energy.

![Cumulative Cash Flow Graph](image_url)
6. Conclusions and recommendations

In a passive cooling design, it is essential that all main elements of the building envelope should either block or reject solar heat gain and try to keep the thermally comfort against the heat gain of summer. Passive design depends on the climatic conditions of the area and should, therefore, be designed accordingly. A passive cooling strategy is often the critical foundational element of a cost-effective zero energy building. In a hot and arid climate, most of the energy load is from mechanical cooling systems, so this load could be reduced by adding elements to the building, such as adding insulation membranes to the building envelope which can significantly reduce energy consumption. This paper shows that external AAC block is strongly recommended to use as an effective solution for saving energy. This paper further investigated potential passive cooling strategies for Nizwa Eco House, a real case study was simulated, and various suggested passive cooling strategies were implemented. The simulation results were analysed and proved the potential for energy reduction and the achievement of optimal thermal comfort if passive cooling strategies were used. The in-depth analysis shows that there is a potential for modification of the cooling load by (47%) after applying these passive cooling strategies than in a situation of baseline scenario. Based on that a positive energy balance was achieved in spite of the effects of weather temperatures and dust.

References


Impact of Outer Shell Design on Energy Performance of Educational Buildings

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Abstract: Sustainability has emerged as the dominant theme in the debate on architecture and building in the last decade. About 50% of the total global electric energy is consumed by buildings with their different functions. There is a close connection between energy and buildings, which, as they are designed and used today, contribute to serious environmental problems because of their excessive consumption of energy and other natural resources. Buildings’ demands for heating, cooling, ventilation, and lighting cause severe depletion of invaluable environmental resources.

This research aims to investigate the green retrofit aspects of existing educational buildings within the Mediterranean climate area as part of the sustainable buildings approach. To achieve its objectives, the research adopted a comparative analytical approach via investigating the important strategies that achieve sustainability and environmental efficiency. Regional models that have applied sustainability retrofit strategies and maintained the use of natural resources in order to conserve energy consumption were analysed and discussed. The retrofitting of a private university’s existing building in Cairo, Egypt, was investigated as the applied case study. A thermal model was built using Design Builder to investigate the building thermal performance. Through the model, the impact of different building material strategies, alternatives, and modifications of outer shell were tested and analysed. Both economic and technical aspects of improving the overall performance of the building and its energy consumption were studied. The research concluded with suggesting the best alternatives for green retrofitting of existing buildings – through modifying its outer shell to reduce its energy consumption as part of achieving more sustainable and environment-friendly building stock.

Key words: Environmental design, Educational buildings, Energy efficiency, Building materials.

Research Problem and Questions:

The research is geared toward answering the following questions: (i) What are sustainable strategies for retrofitting existing buildings? (ii) How far can the thermal performance of existing buildings be improved through architectural renovation? and (iii) How far can outer shell enhancement contribute to existing buildings’ thermal performance?

Aim and Objectives:

This paper aims to explore the potential of retrofitting existing educational buildings in cities within the Mediterranean climate area, in terms of improving their energy consumption through enhancing their outer shell. This is achieved through a combination of objectives as follows: Explore sustainable approaches to improve existing buildings; study the impact of buildings’ outer shell on their thermal performance; identify the thermal characteristics of the walls’ local materials; and investigate the feasibility of enhancing existing buildings’ thermal performance through architectural retrofitting.

Methodological Approach:

The methodology is based on three different approaches: theoretical, analytical, and applied approach. First, the theoretical study leads to the identification of concepts and strategies to achieve sustainability through the retrofitting of existing buildings. This is followed by an analytical study of benchmark case studies of retrofitted existing buildings to evaluate the applied strategies in achieving sustainable educational buildings. Third, the concluded results are tested on one case study building at El-Sherouk University in Cairo, Egypt. This is done through analysing
the building’s existing energy consumption, internal environment control system, its outer shell materials, and their thermal characteristics. Outer shell materials are manipulated as one of these factors affecting thermal performance to test their impact on reducing energy consumption. The most feasible retrofit approaches, both environmentally and economically, are defined to enhance the thermal performance of existing educational buildings. The study concludes with the recommended outer shell retrofit for existing educational buildings in Egypt that would reduce the energy consumption and improve thermal performance as part of the building sustainability approach.

**Theoretical Framework:**

*Global efforts on green retrofit:* Almost half of the produced energy worldwide is consumed by residential, commercial, and public service buildings. Commercial and public sector buildings alone consume up to 23% of the total produced energy worldwide (World Energy Council, 2016). Most of this energy is consumed by existing buildings. The annual replacement rate of existing buildings is only around 3% (El-Darwish, 2017). In the 2030 challenge, the American Institute of Architects (AIA), along with the U.S. Green Building Council, advocated that the construction of new residential and commercial buildings should use half the fossil fuel used on an average by existing buildings and that there should be a gradual increase in the existing buildings’ performance so that by 2030 new buildings are carbon-neutral. Meanwhile, achieving the gradual increase in energy performance of existing residential buildings would require leading-edge energy retrofits (Oluwafemi, 2016). Therefore, rapid enhancement of energy efficiency in existing buildings is essential for a fast reduction in global energy use and promotion of environmental sustainability. Therefore, sustainable retrofit has been a subject of thorough investigations by researchers as a way to improve existing buildings’ thermal performance. Bin et al. (2012) indicated that the energy performance of existing buildings can be improved significantly through sustainable retrofit. Moreover, Flourentzou (2012) also argued that significant reduction in energy use of existing buildings can be achieved through proper retrofit. He also defined renovation as the work that requires upgrading an existing old building and renovating its systems (Flourentzou, 2002).

*Sustainable retrofit:* Sustainable retrofits involve the renovation of an existing building to enhance its environmental performance, reduce water use, and improve the comfort and quality of its internal environment. This could be achieved through either simple treatments such as replacing old parts of the heating or air cooling systems, or sophisticated strategies such as adding new photovoltaic systems to the roof (Ma et al., 2012). Several approaches and strategies for a successful green retrofit have been developed over the last decades. Dascalaki et al. (2011) argued that building typology can be adopted as an indicator of energy performance and can be utilized in the initial energy performance assessment. Caccavelli and Gugerli presented a decision support tool that contains a diagnostic package to evaluate the general state of office buildings in terms of deterioration, energy consumption, and indoor environmental quality (Caccavelli and Gugerli, 2002).

*Building performance assessment:* Richalet et al. (2011) suggested three approaches to evaluating building energy performance: Computation-based approach relying on data collected through energy audits; performance-based approach where input data comes from building utility bills; and measurement-based approach with in situ measurement procedures.
For certain buildings, the proper performance assessment technique should consider user requirements, accurate energy consumption, and main retrofit scope, amongst other things. A reliable estimation of energy consumption enhancements is essential for any sustainable retrofit decision-support system. The performance of different retrofit measures is commonly evaluated through energy simulation and modelling packages. A number of these packages, such as Energy-Plus and e-QUEST, are used to simulate the thermodynamic characteristics and thermal performance of different retrofit alternatives.

**Sustainable retrofit phases**: Sustainable building retrofit aims to determine and implement the most cost-effective technologies to enhance energy performance while maintaining indoor thermal comfort, under a given set of operating constraints. The overall process of a building retrofit can be divided into the following five phases: Project setup, data gathering, and pre-renovation survey; energy audit and performance assessment; identification of retrofit options, which can be achieved through energy simulation models, economic analysis, and risk assessment tools; retrofit plan implementation; and audit and verification of energy savings.

**Building envelope as focus of retrofit study**: The building envelope includes the roofs, walls (including windows), and foundations. Air leakage is considered one of the primary elements that affect building HVAC loads. International Energy Agency (2016) stated that air-conditioning systems consume one-third of the global energy used in public buildings. (I.E.A., 2106) Good building envelopes are the key element for any energy consumption reduction plan and are critical to determining the energy required to heat and cool a building. Needless to say, building envelope design needs to be optimized to minimize heating and cooling loads as a critical part of any long-term energy reduction strategy. In this context, the following three aspects need to be taken into account: Passive heating and cooling technologies are important design considerations. In hot climates, low-cost solutions, such as reflective roofs and walls, low-emissivity (low-e) window coatings and films, and exterior shades, can curtail expected sharp increases in cooling loads. In cold climates, passive heating can be increased with improved building design and from windows through dynamic solar control; integrated facade systems need to be pursued for office buildings to optimize their day lighting performance while minimizing heating and cooling, artificial light and peak loading. greater focus on air sealing with validated results is critical during new construction and is also important for deep envelope retrofits.

**Envelope Components and their impact on energy consumption**: Energy losses through different building envelope components vary significantly based on building type, configuration, climate, vintage, level of construction sophistication, and so on. Several studies illustrate that roofing represents 14% of heating and cooling loads in the United States, while contributing to about 32% in Europe. As for windows, their heating and cooling impact in the United States is 31%, while the same is 15% for Europe (SEI, 2007; Winbuild, 2012). Building materials with different properties respond differently to climatic conditions. The thermal properties of the building’s outer shell, such as types of walls (such as curtain walls) and roofs, dictate its energy consumption and the comfort conditions of its users (Liu, 2008; Soofia, 2006).

**Analysed Case Studies**: **Case study 1 – Improvement of the sustainability of existing school buildings, Italy**: This project aimed to verify – in the field, and in actual buildings – the technical and economic feasibility of sustainable retrofitting of existing school buildings to improve their energy efficiency and sustainability to match the international protocols. An economic evaluation...
was conducted to consider the cost of the main items for retrofitting. Cost items were considered in the economic evaluation compromises; building envelope retrofit, heating systems upgrade, ventilation systems, solar PV, water efficiency cost. All costs were then apportioned according to the gross floor area and expressed in (€/m²). It is important to have a strategic vision regarding having comfortable educational buildings with high indoor air quality that will contribute to improving the learning environment. The economic aspect will always have a greater impact when operating within the public market. The real estate market can ascribe greater value to more sustainable building. The availability of a standard like LEED®, which has an international matrix, is a good thing, considering the consistency between the rules contained in LEED® and Local Building Codes (Giuliano et al., 2013).

**Case study 2: Retrofitting existing university campus buildings:** This study was part of the efforts of turning the University of Applied Sciences Stuttgart (UAS) into a CO₂-neutral university and implementing key principles of sustainability. Air conditioning and lighting systems were examined and compared with other available alternatives. Following a detailed performance analysis, the best applicable options were identified, and the study concluded with the following lessons: Retrofitting measurements combined with continuous monitoring are essential to sustain high energy efficiency and comfort level; user awareness and automated systems help save energy; using an effective evaporative cooling system could save up to 60% of required energy and GHG (Dilay, 2016).

**Analytical study: Retrofitting Egyptian Education Building:**

**Location and climatic context:** University building located in Cairo city. The weather summary of the region shown in Table 1 has the following climatic information of the case study location: latitude/longitude, radiation (direct/diffuse), dry bulb temp, relative humidity, wind direction, and wind speed. From Table 1, it can be found that max wind speed is 4 metres during April and March with 30 to 50 degrees direction. It can also be noticed, from the table, that maximum average monthly temperature is 26 degrees in August, while the minimum is 16 degrees in February.

Table 1. Climatic analysis of Cairo region
**Case study Architecture Description**: The case study of this paper is a four-storey educational building at a private university. Figure 3 shows a 3D model of the study building. Figure 4 shows the air-conditioning system within the building, where most of the classrooms and offices are air-conditioned using split units, with no ventilation or fresh air. Only main spaces such as library and auditoriums have a central HVAC system. Corridors are not conditioned at all.

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**Table 2. Physical characteristics of wall components**

<table>
<thead>
<tr>
<th>Component</th>
<th>layer L (cm)</th>
<th>Conductivity K (Watt/m. c°)</th>
<th>Density P (kg/m³)</th>
<th>Specific C (jol/kg.c°)</th>
<th>Resistance R (m². c°/Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Cement mortar</td>
<td>2</td>
<td>0.93</td>
<td>2000</td>
<td>750</td>
<td>0.021</td>
</tr>
<tr>
<td>2-Solid Cement brick</td>
<td>25</td>
<td>1.4</td>
<td>2000</td>
<td>840</td>
<td>0.178</td>
</tr>
<tr>
<td>3-cement mortar</td>
<td>2</td>
<td>0.93</td>
<td>2000</td>
<td>750</td>
<td>0.021</td>
</tr>
<tr>
<td>U-value</td>
<td></td>
<td>2.51 (W/m².K)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>0.398 (m².K/W)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Curtain walls: 28% of the outer walls are glass areas and curtain walls. They are made up of structural glazed systems, which are double-glazed with thermal transition of 6.12 W/m².K, with a solar heat gain coefficient factor of 0.81 and visible transmission of 0.88. Table 4 shows the optical properties of the glass used in the case study building. Table 3 presents the thermal and optical properties of the glass used in the case study.

Table 3. Thermal and optical properties of the glass used in the case study.

<table>
<thead>
<tr>
<th>Type of glass</th>
<th>SHGC</th>
<th>U-value</th>
<th>VT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single glass 6 mm</td>
<td>0.81</td>
<td>6.12</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Table 4. Physical characteristics of roof layer components

<table>
<thead>
<tr>
<th>Component</th>
<th>layer L (cm)</th>
<th>Conductivity K (watt/m. K)</th>
<th>Density P (kg/m³)</th>
<th>Specific C (jol/kg. K)</th>
<th>Resistance R (m². K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum Plastering</td>
<td>2</td>
<td>0.4</td>
<td>1000</td>
<td>1000</td>
<td>0.05</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>26</td>
<td>2.3</td>
<td>2300</td>
<td>1000</td>
<td>0.11</td>
</tr>
<tr>
<td>Expanded polystyrene</td>
<td>5</td>
<td>0.035</td>
<td>35</td>
<td>1400</td>
<td>1.42</td>
</tr>
<tr>
<td>Preference Concrete</td>
<td>7</td>
<td>0.72</td>
<td>1850</td>
<td>840</td>
<td>0.096</td>
</tr>
<tr>
<td>Sand</td>
<td>5</td>
<td>0.3</td>
<td>1500</td>
<td>800</td>
<td>0.167</td>
</tr>
<tr>
<td>Cement tile &amp; mortar</td>
<td>5</td>
<td>1</td>
<td>1900</td>
<td>840</td>
<td>0.05</td>
</tr>
<tr>
<td>U-value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.47(W/m².K)</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.083(m².K/W)</td>
</tr>
</tbody>
</table>

Note: Thermal resistance for outdoor surface = 0.055 (m².K/W)

Thermal resistance for indoor surface = 0.123 (m².K/W)

Roof characteristics: The roof is composed of six different layers, and the overall value of its thermal resistance is 2.083 m². K/W. Table 4 presents the detailed characteristics of the roof layer components.

Time schedule of building spaces operations:

Weekly working hours of administrative rooms extend from Sunday to Thursday between 9 am and 4 pm, and the whole building is off Fridays and Saturdays. Set working hours for the classrooms inside the building are from 9 am to 4 pm, except during holidays (15 July-15 September). Settings for set-point temperatures for cooling and heating are shown in Figure 5.

Building cooling and heating monthly consumption: As shown in Figure 5, The study building consumes 440,670 Kwh every year; 84% of this consumption goes for cooling, while the rest is used in heating.

Heating is required from December to February, whereas cooling is needed for seven months, between April and October. It can also be noticed that the maximum energy consumption recorded is for June, at 108,549 Kwh.

Bioclimatic Analyses: Thermal simulation package Design Builder was used to analyse how different outer shell materials, layers, and construction perform under outdoor weather conditions. This tool can simulate the performance of the building using different climatic
conditions and different indoor building setups as well. In this study, all sources of internal casual gains were ignored while running the simulation. Accordingly, no occupants or appliances were considered in the model as a source of internal heat gains. This approach was to make a clear evaluation of the impact of the building’s materials and their construction on the building thermal performance.

Discussion: Assessment of the Improvement Levels Predicted to Be Achieved:
The simulation model input data included climate data, envelope components, materials of these components and the thermal characteristics of each of these materials, working schedule, and set point temperature. Entry data were analysed, and energy consumption was estimated. The calculated consumption was compared to the data collected from monthly building bills.

**Impact of applying different types of wall bricks:** Different types of bricks were tested to replace the existing one (base sample). Four different types of bricks were tested. The thermal conductivity of each type is shown in Table 5. Figure 6 shows a cross section of the proposed outer wall layers. The impact of the four types of bricks on energy consumption was tested.

![Wall Section after replacement of Solid cement brick (layer 2) by hollow cement brick, clay brick and light sand brick](Image)

Table 5. Physical characteristics of different types of bricks.

<table>
<thead>
<tr>
<th>Brick type</th>
<th>Layer L (cm)</th>
<th>Conductivity K (watt/m. c°)</th>
<th>Density P (kg/m³)</th>
<th>Specific C (jol/kg.c°)</th>
<th>Resistance R (m². c°/watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Solid Cement brick</td>
<td>25</td>
<td>1.4</td>
<td>2000</td>
<td>840</td>
<td>0.178</td>
</tr>
<tr>
<td>2- hollow cement brick</td>
<td>25</td>
<td>1</td>
<td>1100</td>
<td>880</td>
<td>0.25</td>
</tr>
<tr>
<td>3- clay brick</td>
<td>25</td>
<td>0.6</td>
<td>1790</td>
<td>840</td>
<td>0.416</td>
</tr>
<tr>
<td>4- light sand brick</td>
<td>25</td>
<td>0.13</td>
<td>650</td>
<td>1000</td>
<td>1.92</td>
</tr>
</tbody>
</table>

Figure 7a shows the total consumption during cooling and heating periods, where light sand bricks proved to have enhanced thermal performance and reduced the energy consumption during both periods. Figure 7b shows the percentage of the reduction in the energy consumption as a result of using each of the four tested brick types. It can be noticed from the figure that using light sand brick decreases the energy consumption by 15.6%.

**Impact of adding insulation layer to walls:** Different types and thicknesses of insulation materials were tested. It was found that using expanded polystyrene with different thicknesses increased the total thermal resistance of the walls. Table 6 presents the physical characteristics of the different wall components. It can be noticed from the table that expanded polystyrene has the best physical characteristics.

![Figure 6. Wall Section after replacement of Solid cement brick (layer 2) by hollow cement brick, clay brick and light sand brick](Image)

Table 6. Physical characteristics of wall components.

<table>
<thead>
<tr>
<th>Component</th>
<th>layer L</th>
<th>Conductivity K (watt/m. c°)</th>
<th>Density P (kg/m³)</th>
<th>Specific C (jol/kg.c°)</th>
<th>Resistance R (m². c°/watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Cement mortar</td>
<td>2</td>
<td>0.93</td>
<td>2000</td>
<td>750</td>
<td>0.021</td>
</tr>
<tr>
<td>2-Solid Cement brick</td>
<td>12</td>
<td>1.4</td>
<td>2000</td>
<td>840</td>
<td>0.089</td>
</tr>
<tr>
<td>3- expanded polystyrene</td>
<td>2</td>
<td>0.035</td>
<td>35</td>
<td>1400</td>
<td>0.571</td>
</tr>
<tr>
<td>4-Solid Cement brick</td>
<td>12</td>
<td>1.4</td>
<td>2000</td>
<td>840</td>
<td>0.089</td>
</tr>
<tr>
<td>5-Cement mortar</td>
<td>2</td>
<td>0.93</td>
<td>2000</td>
<td>750</td>
<td>0.021</td>
</tr>
<tr>
<td>U-value</td>
<td></td>
<td></td>
<td></td>
<td>1 (W/m².K)</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td>1 (m².K/ W)</td>
<td></td>
</tr>
</tbody>
</table>
The effect of using expanded polystyrene with different thicknesses on the total thermal resistance of the wall is presented in Table 7.

Table 7. Effect of using expanded polystyrene with different thicknesses on the total thermal resistance of the wall.

<table>
<thead>
<tr>
<th>Insulation layer thickness</th>
<th>Total thermal resistance of wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case (no insulation)</td>
<td>0.398 ((\text{m}^2\cdot \text{K}/ \text{W}))</td>
</tr>
<tr>
<td>2cm</td>
<td>1 ((\text{m}^2\cdot \text{K}/ \text{W}))</td>
</tr>
<tr>
<td>3cm</td>
<td>1.25 ((\text{m}^2\cdot \text{K}/ \text{W}))</td>
</tr>
<tr>
<td>5cm</td>
<td>1.82 ((\text{m}^2\cdot \text{K}/ \text{W}))</td>
</tr>
</tbody>
</table>

The building has an insulated roof with 5 cm expanded polystyrene. Any extra thickness did not make a meaningful difference. Insulating walls contribute to building users’ comfort in hot zones (Dili, 2011). Figure 8 illustrates a cross section of the outer wall with internal insulation (layer 2). Figures 9a and 9b illustrate the effect of using expanded polystyrene with different thicknesses on the overall energy consumption of the building. Figure 14a shows the total consumption during cooling and heating period, where 5 cm proved to have the least consumption during both periods. Figure 9b shows the percentage of reduction in the energy consumption as a result of using each thickness. It can be noticed from the figure that insulating the outer walls with 5-cm thick expanded polystyrene decreases the overall building energy consumption by 15.6%.

**Impact of changing elevation finishing to artificial stone cladding:** In addition to the previous alternatives of wall types and insulation thicknesses, artificial stone cladding with different thicknesses of insulation was also tested. Table 8 presents the total thermal resistance for wall layers with different Insulation layer thickness. Table 9 shows the thermal characteristics of insulation layer with different thicknesses behind artificial stone.
Figure 9. Effect of using expanded polystyrene with different thicknesses on the energy consumption.

Table 8. Physical characteristics of wall components

<table>
<thead>
<tr>
<th>Component</th>
<th>layer thickness</th>
<th>Conductivity K (W/m·K)</th>
<th>Density ρ (kg/m³)</th>
<th>Specific C (J/kg·K)</th>
<th>Resistance R (m²·K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.398 (m²·K/W)</td>
</tr>
<tr>
<td>artificial stone + expanded polystyrene 2cm</td>
<td>2</td>
<td>1.3</td>
<td>1750</td>
<td>1000</td>
<td>0.015</td>
</tr>
<tr>
<td>artificial stone + expanded polystyrene 3cm</td>
<td></td>
<td>0.35</td>
<td>35</td>
<td>1400</td>
<td>0.021</td>
</tr>
<tr>
<td>artificial stone + expanded polystyrene 5cm</td>
<td></td>
<td>0.93</td>
<td>2000</td>
<td>750</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Table 9. Thermal characteristics of insulation layer with different thicknesses behind artificial stone.

<table>
<thead>
<tr>
<th>Component</th>
<th>Thermal resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0.98 (m²·K/W)</td>
</tr>
<tr>
<td>artificial stone + expanded polystyrene 2cm</td>
<td></td>
</tr>
<tr>
<td>artificial stone + expanded polystyrene 3cm</td>
<td></td>
</tr>
<tr>
<td>artificial stone + expanded polystyrene 5cm</td>
<td></td>
</tr>
</tbody>
</table>

The simulation results proved that using an expanded polystyrene insulation layer with different thicknesses behind artificial stone as an external cladding decreases the overall energy consumption of the building. Figure 10 illustrates a cross section of the outer wall with 2-cm artificial stone cladding and expanded polystyrene insulation behind it (layer 2). Figures 11a and 11b illustrate the effect of using this wall configuration with different thicknesses of insulation on the overall energy consumption of the building. Figure 11a shows the total consumption during cooling and heating periods, where 5 cm proved to have the least consumption during both periods. Figure 11b shows the percentage of reduction in energy consumption as a result of using each thickness. It can be noticed from the figure that insulating the outer walls with 5-cm thick expanded polystyrene decreases the overall building energy consumption by 16.78%.
Double layered blue glass curtain walls: As shown in figure 3, the building elevations have large glass areas. Different configurations of these walls were tested. Using double glass panels with air gap can increase curtain walls thermal performance. Several types of glass and several gap widths were tested (Tavares, 2011). Figure 12 shows the effect of using double blue glass (product of Saint-Gobain) in the transparent parts of the building on the energy consumption.

Figure 12a shows the total consumption during the cooling and heating periods, where different types and combinations of glazing were applied. Blue glass proved to have the best impact on energy consumption during both periods. Figure 12b shows the percentage of reduction in energy consumption as a result of using each type. It was found that using double blue glass in the transparent part of the building decreased energy consumption by 10.5%. Changing the outer shell of the building can contribute to energy saving for any existing educational building (Norbert, 2016). Combined treatments were tested for energy consumption saving. Table 10 shows the selected treatments for external walls. Figure 13 illustrates the impact of different treatments on total energy consumption. From the figure, it can be concluded that using double blue glass and expanded 3-cm thick polystyrene behind artificial stone decreases the total energy consumption by about 26.8%.
This paper presented a systematic methodology for appropriate retrofits of existing buildings for energy efficiency and sustainability. An overview of previous studies related to the investigation and evaluation of energy performance and economic feasibility of different retrofit technologies utilized in several cases was provided. There is a large body of research on building retrofits available in the public domain. However, existing buildings continue to be upgraded at a very low rate. For instance, existing commercial building stock is currently being retrofitted at a rate of only 2.2% per year (Olgyay, 2010).

Previous studies have demonstrated that energy and environmental performance of existing buildings can be improved significantly through appropriate retrofits. Most of these studies were carried out using numerical simulations. Consequently, the actual energy savings due to the implementation of retrofit measures in real buildings may be different from the estimations. More research with practical case studies is needed to help increase the level of confidence in potential retrofit benefits. Obtaining better data for existing building stock and materials and systems within local markets will allow for better programmed development of building envelopes, besides enabling policy makers to address the most important elements for the particular climate, building characteristics, and market.

The most effective solution is to investigate the available alternatives, and invent the best technical-executive procedures that suit the existing building context and its specific features. Comprehensive and detailed data for energy performance of building envelope components are hard to obtain; consequently, saving opportunities are even more difficult to predict because they are highly dependent upon base loads. This study utilized one of the thermal performance assessment packages, “Design Builder”, to analyse the effect of envelope components and their design on reducing energy consumption. The factors include exterior wall construction materials, thermal insulation, as well as glass type. Simulation proved that the total energy consumed can be reduced through a green retrofit process. This process includes changing the external wall materials and layers of any existing educational building. Reconstructing the envelope with carefully selected materials for external walls can have a great impact on energy consumption and internal space comfort.

Analysing the results of the tested case, it can be concluded that using light sand brick as a construction material decreases the energy AC system electric consumption by 15.6%. The results also showed that insulating external walls with 5-cm thick extended polystyrene decreases the air conditioning system’s energy consumption by 15.6%. Moreover, the results proved that using a 2-cm thick artificial stone cladding with 5-cm thick insulation can decrease energy consumption by 16.78%. Studying glass types showed that using double layered 12 mm blue glass with 6 mm air space can reduce energy consumption by 10.50%. The study concludes by suggesting green retrofits with a comprehensive approach that considers both economic and environmental aspects. This approach will facilitate user comfort with 26.8% reduction in energy consumed. Appropriate selection criteria and weighting factor assignment are

Table 10. Selected treatments for energy saving consumption

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Energy saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue glass</td>
<td>10.5%</td>
</tr>
<tr>
<td>Artificial stone+ expanded</td>
<td>14.92%</td>
</tr>
<tr>
<td>polystyrene 3 cm</td>
<td></td>
</tr>
<tr>
<td>Combined treatment</td>
<td>26.8%</td>
</tr>
</tbody>
</table>

Figure 13. Impact of different treatments on the total energy consumption
essential in the formulation of multi-objective optimisation problems to select the most cost effective retrofit strategies. The major concerns of building owners with regard to retrofits should be carefully considered during the development of the optimisation problem.

To sum up, there is still a long way for building scientists and professionals to go in order to make existing building stocks more energy efficient and environmentally sustainable. To achieve building resilience keeping in view the effects of climate change, more research on low energy adaptive strategies for building applications is needed. Further research work and investigation in this regard are needed to facilitate cost effective building retrofits.

References


www.iea.org/etp/buildings.


A state of the art review of the impact of Vertical Greenery Systems (VGS) on the energy performance of buildings in temperate climates

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Abstract: Rapid urbanization and climate change concerns have led to a growing drive to integrate nature into the built environment. It is expected that London will face increasing risks of flooding, overheating and drought, through hotter drier summers and warmer wetter winters. In response, the Mayor of London adopted new policies for encouraging the use of living roofs and green walls. Greenery systems are considered as promising solutions for improving energy and thermal efficiency of buildings as well as reducing pollution, encouraging biodiversity and water runoff, reducing Urban Heat Island (UHI) effects and improving the microclimate overall. The research aims to review the current state-of-the-art literature concerning the potentials and limitations of vertical greenery systems on energy and thermal performance of buildings in temperate climates. This review paper synthesises and summarizes the literature with regards to vertical green systems (VGS) when used as a passive design strategy to enhance energy savings in buildings. From the review of the literature, some key aspects to consider when designing VGS are outlined, such as climate influence, the plant species grown and the different operating mechanisms as associated such as shade, evapotranspiration, insulation and wind barrier. The results achieved from the literature review clearly indicate that green walls may be considered as key solutions to mitigate operational energy consumption of buildings as well as provide thermally comfortable indoor and outdoor environments. The results of this research will prove useful to builders, architects, engineers and policy makers as it will provide an in-depth understanding of the potential of VGS to mitigate building-related energy consumption in a renewable, sustainable, energy-efficient and cost-effective way.

Keywords: Green and living Walls, Vertical greenery systems, Green Façade, Energy Performance, Passive design

Introduction

Living walls and green facades “vertical green systems” are two main ways for integrating vegetation into buildings. Green roofs have been classified, discussed and investigated in many research studies (Green Roof Thermal Performance’, 2006, ‘Cool Roofs for improving thermal performance of existing EU office buildings’, 2016; Grant and Lane, 2006; Köhler, 2006; J K Lanham, 2007; Collins et al., 2017; Koura et al., 2017; Mahmoud et al., 2017; Barozzi et al., 2017; Vera et al., 2017), in contrast vertical green systems “VGS” have not been sufficiently studied regarding its systems, components, benefits and environmental impact particularly in temperate climates.

This might be because it may be more practical to install greenery systems on flat levels and roofs compared to applying it vertically, in addition, its lower cost due to less specialised skills required in the process (Pérez et al., 2014). However, VGS could have a more significant impact on the built environment and microclimate, as the building surface area of facades is much larger than roof area.

Temperate climate

Sometimes authors do not specify the climate of the study, other times they mention it without using a recognised climate classification, and thus comparing them is problematic. Koppen climate classification system is used due to it is recognition worldwide.

It could be classified as the most wide-ranging climate system across the world and it is classified into two types (ISC-AUDUBON, 2013; GA, 2018): Maritime temperate regions which are located near coastlines where oceanic and sea wind deliver more rain and temperature are fairly steady across the year. Such regions include
Western Europe the UK particularly, while Continental temperate regions are usually warmer in summer and colder in winter. In temperate climates, buildings are designed to remain cool in the warm summers and be warm in cold winters that could be through seeking solar radiation gain in winter and providing summer shading (HH, 2013). Building materials are also designed with moderate thermal mass, with moderately-sized openings and adequate thermal insulation properties, in order to provide satisfactory conditions for most of the time, through overcoming over-heating in summer and cooling in winter (SKAT, 1993).

Few studies on the thermal impact on the energy performance of VGS in a temperate climate was found (Martin and Knoops, 2014), Thus, this paper discusses the findings from an extensive review of the literature concerning the impact of VGS on building energy performance in temperate climates.

**Vertical greenery systems (VGS)**

Vertical Greenery Systems are known as vertical gardens or bio-walls. They mainly consist of vertical structures which are fitting vertical expansion whether being attached to the wall of apart from it. It is also classified based on its complexity level, as they could be with a simple configuration or a high-tech design (Pérez-Urrestarazu et al., 2015). Based on plant type, supporting system and its material, etc. Based on that, there are two different types of VGS, one; is a living wall and the other is a green façade (K€ohler, 2008; Manso and Castro-Gomes, 2015). They look similar but their planting systems are different.

**The Green Façade (GF)**

It is a type of vertical greenery system at which the building facade is climbed by plants either from the soil at the base of the building or from the top through planter boxes. It may take between 3-5 years for the plant to cover the whole façade and be fully grown over. It might harm the façade due to its strong roots such as the English Ivy (Othman and Sahidin, 2016). GF has several advantages as having no materials involved (growing media, support and irrigation), low-cost low maintenance, while its disadvantage lays in limited plant selection, slow surface coverage and its scattered growth along the surface (Manso and Castro-Gomes, 2015). Green Façade is divided into direct and indirect “ double skin “ green façade (A.M. Hunter, N.S.G. Williams, J.P. Rayner, L. Aye, D. Hes, S.J. Livesley, 2014; T. Safikhani, A.M. Abdullah, D.R. Ossen, M. Baharvand, 2014; E. Cuce, 2016),(K. Perini, 2013).

![Figure 1](image-url)

**Figure 1 a) Showing planter box at the bottom with plants directly on the wall, b) planter box at the bottom with plants on supporting structure, c) planter box at the bottom of floors with plants of supporting structure (Shamsuddeen Abdullahi and Alibaba, 2016)**

Direct green façade is a traditional green façade at which climbing plants stick to the building façade through their adhesive roots, without the need for structural support (S. Isnard, W.K. Silk, 2009; A.M. Hunter, N.S.G. Williams, J.P. Rayner, L. Aye, D. Hes).
On the other hand, indirect green façade is a double skin green façade at which structural systems as modular trellises, stainless steel mesh or stainless steel cable are used to support vertical climbing plants through the second layer of façade at a desired distance from façade (Pérez et al., 2014; Manso and Castro-Gomes, 2015; E. Cuce, 2016).

**Living Wall System (LWS)**

The second type of VGS is the LWS which is composed of a mix of different plants usually used for green walls. Special vertical planting medium allows ground-cover plants to be planted vertically whether in a modular or a continuous system, which is made of one continuous piece of felt-layer or a single continuous concrete block (Dover, 2015; Charoenkit and Yiemwattana, 2016). The structure is metal, plastic, or other materials which are connected vertically by a structural frame. More maintenance and care is needed besides its structural load, in terms of fertilizing, trimming plants, removal and replacement of dead plants (Othman and Sahidin, 2016).

LWSs have several advantages such as the benefit of uniform growth, wide plant variety can be used, easily maintained due to its modular units which could be easily replaced besides its higher aesthetic value. While its disadvantage lays in its frequent maintenance, complex system, high water and nutrients consumption, high environmental burden and its heavy weight (Manso and Castro-Gomes, 2015). There are three systems of living walls which differ according to its function, design and construction system and materials and whether it is being used within the interior or exterior spaces (Loh, 2008).

![Figure 2 a) Panel system (Left), b) Felt system (Middle), c) Container/ Trellis system (Right)(SAA, 2014)](image)

The first type is Trellis / Container System, in which containers are used to grow plants and climb onto trellises irrigation is done by controlled drip-lines. Felt System is the second type, made of felt pockets of growing medium attached to a waterproof packing where plants are grown, which is then connected to a structure behind. The felt is kept moist with water which contains plant nutrients. The third system is the Panel System which usually consists of pre-planted panels and connected to a structural system with a mechanical irrigation system.

**Benefits of VGS in temperate climates**

VGS potentials and positive impact on buildings through several aspects, socially, economically and environmentally which is the main aim of this paper to determine the influence and impact on building energy performance.
Environmental Benefits

Three main factors are considered in this paper as the key parameters for determining the impact of VGS as a passive technique for energy saving in a building through thermal insulation, Carbon emissions reductions and urban heat island effect.

There have been several approaches and studies on the advantages and disadvantages of VGS on energy performance in temperate climates. These aspects have been studied through synthesising and analysing outcomes of key studies.

The main aspects of focus are the orientation of the VGS, climate and sub-climate classification, the season of growth, duration of the study and finally whether empirical data analysis or modelling and simulation was used.

Key considerations for VGS energy performance (EP):

VGS as a passive tool for energy savings in buildings is mainly controlled by key factors, which influence its EP impact on building fabric, thus it should be well considered. The first factor is the climate influence, which is not only affecting the microclimate around the building, but it also affects the plant species used and how it will grow. The type of VGS used is the second factor, whether it is direct, indirect green facade or living wall. The third factor is the plant species, whether it is evergreen or deciduous or climbing, etc. the façade orientation is very important as different plant species require different orientation, as well as the different impact of each species on building EP depending on which façade orientation it is applied to. Finally, the particular study focus and concern were outlined in order to illustrate the key findings and their influences in temperate climates.

Based on these considerations we have developed three study tables for VGS classification were carried out to illustrate and analyse the research which was carried so far on VGS influence on EP in Temperate climate. It was classified into three tables which are direct, and indirect green facades and living walls.

Direct green facades studies on VGS as a passive tool for improving energy performance in temperate climate

12 study has been carried out for direct green façade in a temperate climate. Most of the studies have been carried out in summer with the main focus on its thermal performance.

There was no focus on carbon reductions although it was mentioned in Hasim Altan study through calculating the LCA of green facades, while with one study on wind study impact on energy performance.

Table 1 Direct green facades studies

<table>
<thead>
<tr>
<th>Author / Year</th>
<th>Location</th>
<th>Koppen classification</th>
<th>Study Period</th>
<th>Plant Species</th>
<th>orientation</th>
<th>Model/ Real analysis</th>
<th>Study Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Hoyano, 1988)</td>
<td>Tokyo, Japan</td>
<td>Cfa</td>
<td>Summer</td>
<td>Boston ivy</td>
<td>West</td>
<td>Real</td>
<td>Thermal and cooling load</td>
</tr>
<tr>
<td>(Eumorfopoulou, 2009)</td>
<td>Thessaloniki, Greece</td>
<td>Cfb</td>
<td>Summer</td>
<td>Boston ivy</td>
<td>East</td>
<td>Both</td>
<td>Thermal performance</td>
</tr>
<tr>
<td>(Sternberg, Viles and Cathersides, 2011)</td>
<td>Byland, Abbey, Ramsey, Oxford, UK</td>
<td>Cfb</td>
<td>All Year</td>
<td>Hedra Helix</td>
<td>West, South</td>
<td>Real</td>
<td>Wall surface temperature</td>
</tr>
<tr>
<td>(Perini et al., 2011)</td>
<td>Delft, Netherlands</td>
<td>Cfb</td>
<td>Autumn</td>
<td>Hedra Helix</td>
<td>North, West</td>
<td>Real</td>
<td>Wind Speed</td>
</tr>
<tr>
<td>(Cameron, Taylor and Emmett, 2014)</td>
<td>Reading, UK</td>
<td>Cfb</td>
<td>Summer</td>
<td>Hedra Helix, Stachys byzantina</td>
<td>North, South</td>
<td>Real</td>
<td>Wall surface temperature</td>
</tr>
</tbody>
</table>
In-Direct “double” green facades studies on VGS as a passive tool for improving energy performance in temperate climate

All indirect green façade energy performance related studies have been carried out through real analysis with a general main focus on South façade with the thermal insulation as the main goal. Compared to direct green façade, indirect green façade are quite not common due to its higher cost which could be avoided by using the direct green façade.

Table 2 In-Direct “double” green facades studies

<table>
<thead>
<tr>
<th>Author / Year</th>
<th>Location</th>
<th>Koppen classification</th>
<th>Study Period</th>
<th>Plant Species</th>
<th>orientation</th>
<th>Model/ Real analysis</th>
<th>Study Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Hoyano, 1988)</td>
<td>Tokyo, Japan</td>
<td>Cfa</td>
<td>Summer</td>
<td>Boston ivy</td>
<td>West</td>
<td>Real</td>
<td>Thermal and cooling load</td>
</tr>
<tr>
<td>(Koyama et al., 2013)</td>
<td>Chikusa, Japan</td>
<td>Cfa</td>
<td>Summer</td>
<td>Bitter melon, Morning glory</td>
<td>South</td>
<td>Real</td>
<td>Wall surface temperature</td>
</tr>
<tr>
<td>(Ip, Lam and Miller, 2010)</td>
<td>Brighton, UK</td>
<td>Cfb</td>
<td>--</td>
<td>Virginia Creeper</td>
<td>South, West</td>
<td>Real</td>
<td>Wall surface temperature</td>
</tr>
<tr>
<td>(Perini et al., 2011)</td>
<td>Rotterdam, Netherlands</td>
<td>Cfb</td>
<td>Autumn</td>
<td>Heredia helix, Vitis</td>
<td>--</td>
<td>Real</td>
<td>Wind speed</td>
</tr>
<tr>
<td>(Gabriel Pérez et al., 2011)</td>
<td>Lleida, Spain</td>
<td>Csa</td>
<td>All year</td>
<td>Parthenocissus tricuspidata, Lonicera japonica</td>
<td>South East (SE)</td>
<td>Real (physica l model)</td>
<td>Illuminance and light transmission factor values, Thermal insulation, Relative Humidity, Thermal comfort</td>
</tr>
</tbody>
</table>

Living wall studies on VGS as a passive tool for improving energy performance in temperate climate

8 studies have been carried out for living walls in a temperate climate. Most of the studies have been carried out in summer, South and South West façade with the main focus on its thermal performance. There was no focus on carbon reductions although it was mentioned in Hasim Altan study through calculating the LCA of green facades, while with one study on wind study impact on energy performance. Most of the studies have been carried out for real case studies.

Table 3 Living wall studies

<table>
<thead>
<tr>
<th>Author / Year</th>
<th>Location</th>
<th>Koppen classification</th>
<th>Study Period</th>
<th>Plant Species</th>
<th>orientation</th>
<th>Model/ Real analysis</th>
<th>Study Focus</th>
</tr>
</thead>
</table>

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Table 1, Table 2 and Table 3:

<table>
<thead>
<tr>
<th>(Cheng, Cheung and Chu, 2010)</th>
<th>Wuhan, China</th>
<th>Cfa</th>
<th>Summer</th>
<th>Six different species</th>
<th>West</th>
<th>Real</th>
<th>Thermal performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(G Pérez et al., 2011)</td>
<td>Benthnizen, Netherlands</td>
<td>Cfb</td>
<td>Autumn</td>
<td>Evergreen species</td>
<td>West</td>
<td>Real</td>
<td>Wind speed</td>
</tr>
<tr>
<td>(Olivieri, Olivieri and Neila, 2014)</td>
<td>Colmenar, Spain</td>
<td>Csa</td>
<td>Summer</td>
<td>Sedum species</td>
<td>South</td>
<td>Real</td>
<td>Thermal-energy performance</td>
</tr>
<tr>
<td>(Mazzali et al., 2013)</td>
<td>Lonigo, Venezia (B) Pisa, Italy</td>
<td>Cfa, Csb</td>
<td>Summer</td>
<td>Several, shrub, herbaceous and climber species</td>
<td>(A) South (B) South, West and East</td>
<td>Real</td>
<td>Energy performance</td>
</tr>
<tr>
<td>(Ottelé et al., 2011)</td>
<td>Several Temperate Climates</td>
<td>Cf</td>
<td>--</td>
<td>Several species</td>
<td>All</td>
<td>Both</td>
<td>Thermal performance</td>
</tr>
<tr>
<td>(Altan et al., 2017)</td>
<td>Sheffield, UK</td>
<td>Cfb</td>
<td>All</td>
<td>Hedra Helix</td>
<td>all</td>
<td>Real</td>
<td>Life cycle Energy and Carbon savings</td>
</tr>
<tr>
<td>(Bianco et al., 2017)</td>
<td>Turin, Italy</td>
<td>Cfa</td>
<td>Summer, Winter</td>
<td>Lonicera nitida</td>
<td>South</td>
<td>Real</td>
<td>Thermal Performance</td>
</tr>
</tbody>
</table>

Key findings based on VGS EP studies

It is clear that studies undertaken in temperate climates have been mainly focusing on GF more than LW studies that might be due to its low cost and low maintenance, in addition to requiring less expertise in planting field.

It was found within the same seasons in (Eumorfopoulou and Kontoleon, 2009; Perini et al., 2011; Yoshimi and Altan, 2011; Mazzali et al., 2013; Bolton et al., 2014) that winter in Greece, UK, Netherlands and Italy are different in findings regarding VGS performance. Although they are located within the same Koppen classification in warm temperate, fully humid, warm summer “Cfb”, based on authors classification for their cities. Notably, after further investigation into the results from those studies, it was found that several cities are not located within the same sub-climate zone based on Koppen climate. Leading to inconsistency in VGS performance particularly between oceanic and Mediterranean temperate climates.

Comparing the Mediterranean and temperate climates it was found that both direct and indirect GF systems in both climates have the same amount of reduction in heating by 1.2% and cooling by 43%. While temperature reduction was 4.5°C and 2.6°C for the Mediterranean and temperate climates respectively. Thus the temperate Mediterranean has higher saving than Temperate oceanic due to higher energy consumptions in summer for cooling. Energy saving for LW with planter boxes and felt system had the same percentage of savings in both climates 6.3% and 4% respectively. While temperature reduction was found on both systems with 4.5°C and 2.6°C for the same systems. While energy saving for cooling was 45% for both systems in a Mediterranean climate, while it was not applicable in a temperate climate (Ottelé et al., 2011).

It has also been noticed that several studies are not illustrating the same climatic properties of its zone when carrying out a study. Which was clear in (Bolton et al., 2014), at which his case study was in two winters and it was extreme cold snowy winters which are not representing the basic case of the climate in Manchester, UK. Most of the studies have been undertaken on evaluating the thermal performance of VGS either wall surface temperature, indoor temperature or both. While very few studies focused on wind speed and carbon savings which is also contributing in the EP.

Studies which was carried out was mainly focusing on summer season, south or south-west façade. Which shows the main goal of these studies has been more concerned about
lowering the cooling load. There was a lack of long-duration studies for a whole year and for several years, which would have been a great way to show if VGS has an influence on climate change adaptation. Wall surface temperature was the main concern in several studies, showing savings in average between 11 to 20.8 °C in the summer period and 5–16 °C in autumn, while indoor thermal improvements ranged between 1-2°C.

A thermal regulation feature of green wall systems highly depends on vegetation type, plant intensity and orientation. The vegetation layer should not block the summer winds but should reduce the cold winter wind. Furthermore, direct solar radiation to south wall and roof is necessary for places with high heating degree days in a temperate climate. Expanding the greenery surfaces in cities by about 10% or more can help minimise the local temperature rise projected for the upcoming future.

**Thermal Improvement** Table 1, Table 2 and Table 3

There are several factors affecting thermal performance of LW as LW types; substrate type and depth, plant characteristics, air cavity and environment impact on plant performance as limited light, high wind speed, and water shortages (Charoenkit and Yiemwattana, 2016). (Bolton et al., 2014) found that, the ivy covering reduced temperature fluctuations, increased the mean external wall temperature by 0.5 °C, while on average 1.4 °C warmer at night and 1.7 °C cooler in the middle of the day, leading to 8% reduction in energy loss.

Temperatures above 12.2 °C the ivy covering increased energy loss due to blocking the warm sun, although the covering was more effective on cold days. Evergreen living walls can reduce heating costs, particularly when placed on the North of buildings, while the South side deciduous climbers are more effective as it allows warm sunlight to get into the building. (Yoshimi and Altan, 2011) proved that plant cover improved indoor thermal comfort in both summer and winter, and reduced heat gains and losses through the wall structure.

This resulted in lower annual energy loads for heating and cooling and these effects were more significant in the case of plant cover on lightweight buildings. Plants on south or west walls appeared to be the most effective to decrease daytime indoor room temperature in summer. In cold conditions, the foliage layer increased the minimum temperature when it was applied on the north and west facing walls. Vegetation could also have negative effects such as increasing the night-time indoor temperatures in summer and obstructing daytime solar heating in winter.

Vegetation also reduced the heat gains and losses by conduction through external walls. This resulted in lower energy loads for mechanical heating and cooling. (Besir and Cuce, 2018) showed that external surface temperature is observed to reduce in the range of 3.7–11.3 °C while increasing the percentage of foliage between 13% and 54%. The temperature difference between living wall and the bare wall is 1–31.9 °C. The range of the heat flux reduction is reported to be 30–70 W/m² during daytime and 1.5 W/m² during the night. Wind speed within foliage decreases nearly 0.43 m/s compared to 10 cm distance from the bare wall and the wind speed inside vegetation is found to be zero.

**Energy Improvement:**

The foliage covering has three properties that will affect the heat transfer amount between the indoor and the outdoor climate which are wind speed reduction, solar radiation reduction and evaporation. The annual energy consumption decreased by almost 1%. Due to a decrease in cooling and increasing heating loads (Oosterlee, 2018).

Annual energy loads for heating and cooling were significantly reduced by vegetation more significantly through the green roof system in comparison to the green wall system.
through roof level, while the opposite was noticed through the whole building façade vegetation case (Lee, 2014).

(Oosterlee, 2018) Changing structure from heavy to light structure, increased energy consumption by 41% leading to energy saving by 24%. Attaching the LW system to the poorly insulated heavyweight structure caused the annual energy consumption to drop from 18.35 kWh to 14.65 kWh. The LW system can have a significant influence on the resistance value (0.9 m2 K W⁻¹) of the wall. The VGS energy savings aspect of could be significantly beneficial when a high cooling demand is required for the building and with neglecting heating demand.

Therefore, these type of buildings is found in dry, tropical and Mediterranean climate zones. Throughout uninsulated physical model, mean energy consumption was reduced by 21, 37% compared to bare cuboids during the first & Second winter, while under extreme scenarios, GF has increased energy efficiency from 40-50% leading to wall surface temperatures enhancement by 3°C (Cameron, Taylor and Emmett, 2015).

Based on (L. Malys, M. Musy, 2014), 1-2°C is the temperature reduction in the LW substrate layer. LW Energy performance is varied based on façade orientation in Portugal temperate climate (Csa), as with North walls a reduction of 24.4-28.6% of heating loads followed by west wall then East walls by 8.2-13.3% and 6-11.2% respectively (J.S. Carlos, 2014; Charoenkit and Yiemwattana, 2016).

(Ottelé et al., 2011) No difference was found in the air temperature and wind profiles starting from 1 m in front of the façades till inside the foliage. Inside the foliage of the direct and indirect systems and inside the air cavity of the LWS a low (respectively 0.08 m/s and 0.1 m/s) wind velocity was measured. The higher wind velocity found inside the air cavity of 20 cm thickness of the indirect greening system demonstrates that it is also possible to speak about an optimal air cavity thickness for greening systems (around 40-60 mm). Due to the reduction of wind velocity measured (<0.2 m/s), the exterior surface resistance (Re) could be equalized to the interior surface resistance (Ri). This affects the total thermal resistance of the façade which results in energy savings.

The payback period of direct GF ranges between 16-24 years, 16-42 for indirect GF, Thus GFs are more economically sustainable than LW, which its payback time is not less than 50 years. The living wall system analysed in this study can not be considered economically sustainable due to high (compared with the other greening systems analysed in this study) installation and maintenance costs (Perini and Rosasco, 2013).

Carbon sequestration (CS)

Considering the carbon reduction tax as 20$/ton (Kyoto Protocol) the annual benefit in carbon reduction: 0.055X10⁻³ to 0.065X10⁻³ €/m²/year.

In London, payments “£60/tonne.co2” should be paid in instead of remaining carbon emissions for developments which will not meet the targets of achieving zero carbon for residential buildings on October 2016 followed by non-domestic by 2019, which should already achieve 35% of carbon reductions (STROMA, 2014; STORMA, 2018). Thus the required cost of a dwelling lifetime is (£60 x 30 years = £1,800/t.CO2).

Owing to carbon emissions environmental hazardous, most of the countries are targeting to minimizing their emissions, thus cutting energy consumption is a must in addition to enhancing green infrastructures as a solution key (Besir and Cuce, 2018).

LW have poorer performance than green roofs (GR) in CS which is 0.14-0.98 kg C/m² for LW and 0.375-30.12 kg C/m² for GR even though using same plants. LW CS is similar to GR sedum green substrate with 6cm depth, as it is concluded that there is a relationship between
CS and substrate depth, at which the deeper the substrate is the higher CS is occurring (Getter et al., 2009; L.J. Whittinghill et al., 2014; H. Luo et al., 2015; Charoenkit and Yiemwattana, 2016)

**Urban Heat Island Mitigation**

Climate change may increase the number of heat-related deaths in the European countries rising from 152,000 to 239,758 a year by 2080, leading to 50 times death rise. While in the UK by 540 per cent increase by 2080 as nearly 11,000 persons could die every year as a result of heatwaves. On another hand, It is predicted a 118% spread of urban areas in the UK and a 148% increase in people living flooding areas (Martin Bagot, 2017).

Dr Forzieri declared that continuous urbanisation will amplify urban heat island effect in that built-up area in which heat is trapped and absorbed inside canyons (Giovanni Forzieri, 2017). South East of UK temperatures in Summer are expected to go up to 3.5°C, 5°C warmer by the 2050s and 2080s respectively in addition to that Urban Heat Island (UHI) adds 5-6°C to summer night time temperatures (Hulme et al., 2002). London centre will face up to 9°C in temperature higher than the surrounding greenbelt with expectations to frequency increase of these effects (GLA, 2006).

For all European countries climates examined in a study by Jones, green walls have a deeper influence than green roofs. Yet, green roofs have a greater impact on the roof level, consequently, at the urban scale. They could mitigate raised urban temperatures, through applying that to the whole city scale, which can lead to major energy savings, additional “human-friendly” urban spaces, ensuring a sustainable future, from a thermal perspective, for urban inhabitants (Alexandri, 2017)

In general, green walls have a stronger influence within the canyon than green roofs, but they do not affect the temperature of the air masses above the canyon.

Due to VGS plants evapotranspiration, Institute of Physics in Berlin illustrated that a mean cooling value of 157kWh/day could be achieved based on a 56 planter boxes study on 4 floors of their building (Schmidt, Reichmann and Steffan, 2018). A study made by (Gill et al., 2007) for green infrastructure potential in cities climate change adaption by 2080 found that maximum surface temperature is reduced by 2.5°C through increasing 10% of green cover. While removing the same percentage would lead to 7°C increase in surface temperature (Steven W. Peck, 2009). The frequency of heat-wave events is probably rising across Europe and the UK (Robertson, 2016).

While (Alexandri, Jones and Doussis, 2005), showed that Green walls have a higher impact than green roofs within the canyon, while green roofs have a larger influence at the roof level and urban scale. Green roofs and green walls combination lead to the highest mitigations of urban temperatures, even for cold climates as London and Moscow. Which got the least benefits in temperature reduction 1.7 - 2.1C and maximum from 2.6 -3.2C for the green-walls, while it ranged between 3.0 - 3.8C and maximum from 3.6-4.5C for green all case.

**The Major Limitations for Implementing VGS in a temperate climate** (GRHC, 2009; AMY STOREY, 2015; MAYRAND AND CLERGEAU, 2018)

VGS are similar to gardens, thus maintenance is required regularly for different systems parts as weeding, irrigation and other gardening activities as fertilizing, depending on plant type and season besides installation costs (RA Francis and Lorimer, 2011). Recent technologies showed that green systems reached 28% cost reduction due to industry innovations in 2017 (Martin and Knoops, 2014), on top of an affordable cost study which was carried out by (Oluwafeiyikemi and Julie, 2015), who afforded VGS for low-income neighbourhood in Nigeria living on less than £1 from recycled materials.
The structure could be a barrier especially for retrofitted buildings due to its load impact, therefore the vegetation weight should be considered. While calculating structural load, although through using light weighted recycled plastics and media with decrease total weight considerably. Patric Blanc also designed much light weight VGS with less than 6 lbs./ft², Survivability of different vegetating species is a concern as not all plants can be surely guaranteed to grow and flourish. Thus based on the climate, it is advised to prioritize the survivability than the plant beauty.

VGS can protect buildings from fire if they followed general main guidelines in addition to being well irrigated and maintained. While if not, only 10% is flammable material VGS policies might be more problematic for smaller communities, due to the lack of applying VGS in the construction sector. However, larger cities started to implement programs and incentives to encourage green infrastructures. VGS enhances wildlife habitat as birds and insects which might not be wanted by building occupants, who might ask for more protection.

**Conclusion**

This review classifies, analyses and summarizes the literature on (VGS) as a passive tool for energy savings in buildings in a temperate climate. Generally, VGS can be a useful tool for thermal control of buildings, leading to carbon and energy savings. Thus when studying VGS influence on passive energy savings, these points should be taken in considerations as, VGS type, sub-climate classification, plant species, season and façade orientation.

The review classified the different types and systems of VGS, then grouping direct, indirect green façade and living walls studies in three different tables in order to summarize the studies which were carried out. Afterwards, the outcomes and conclusions are classified into three parts, which are building energy performance, carbon reductions and urban heat island effect. Then limitation of applying VGS in a temperate climate are being mentioned.

Evergreen living walls can reduce heating costs, particularly when placed on the North of buildings, while the South side deciduous climbers are more effective as it allows warm sunlight to get into the building. Annual heating and cooling energy loads are more significant in the case of plant cover on lightweight buildings with south or west walls in summer. While in cold conditions, the foliage layer increased the minimum temperature when it was applied on the north and west facing walls.

VGS in Temperate Mediterranean is performing better than temperate oceanic due to higher energy saving for cooling during summer days, which is confirming the benefits of VGS as passive insulation technique for buildings.

VGS is more effective, when insulation is not existing or as a method of existing insulation enhancement, through convective heat loss reduction and decreasing wind chill beside precipitation protection. Decreasing wind speed leads to equalizing internal and external wall surface thermal resistance.

VGS installation on efficient buildings is not economically viable in cold climates from energy wise due to low heating energy savings due to blocking warming sunlight in heating seasons (Feng and Hewage, 2014). One of the clear conclusions is that the payback time is so long for the VGS “energy-wise”. While the payback period of direct and indirect GFs are more economically sustainable than LW. VGS is related to GDP and countries motivations, as it increases within countries with higher GDP and dense cities.


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Impacts of climate change on a Zero Energy Building in the Brazilian Savannah

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Abstract: Considering the phenomenon of global warming and the need to reduce its causes and effects, the approach to the production of sustainable buildings has become more and more important. The increase in external temperatures results in higher energy consumption to maintain internal thermal quality, with Zero Energy Building (ZEB) being an alternative and a mandatory trend in some countries. ZEBs are buildings with energy efficiency strategies that also have its own energy generation source. The aim of this study is to demonstrate how climate change will impact the ZEBs, considering as a parameter the Fourth Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). The object of study is a house located at latitude 15°S in the centre of South America, and it was used computational simulation to create future climate scenarios of 2020 (2011 to 2040), 2050 (2041 to 2070) and 2080 (2071 to 2100). Energy consumption was predicted in the current scenario with and without photovoltaic energy generation, establishing a ZEB base case. Results showed that there will be an increase in energy demand over the years, and showed that the photovoltaic system will become out of date, that is, it will not able to meet this new demand, from around 14.1% by the 2020s, 26.3% for the 2050s and 40.2% for the 2080 period. It provides subsidies for reflection on buildings energy consumption trends and de-characterization of the ZEB concept in a short period.

Keywords: Sustainable buildings, photovoltaic energy, global warming.

Introduction

Since industrial revolution, greenhouse gas concentrations have been increasing as a consequence of natural phenomena and anthropogenic actions, such as the burning of fossil fuels and accelerated urban density, which directly alter global mean temperatures. In recent years, discussions about causes and effects of this phenomenon, associated with the concern about issues of energy demand and consumption have been increasing and being taken as a focus in several world debates. NASA Goddard Institute for Space Studies found that global surface temperatures have increased by about 0.8°C compared to the last decade (Hansen et al., 2010).
The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), in order to compose scientific knowledge on climate change motivated by anthropogenic actions and based on greenhouse gas emissions. Since the first report in 1990, projections of global mean temperature have increased from 0.15°C to 0.30°C per decade (IPCC, 2007).

In this context, climatic conditions impose new impacts on buildings and cities, not only by the increase in global average temperature but also by changes in other climatological variables, which consequently increase the energy consumption of buildings. The generation of energy destined for anthropogenic use are the main sources of greenhouse gas emissions in the world (CBCS, 2014). According to the International Energy Outlook 2017 report (EIA, 2017), the total world energy consumption in 2015 was 575 quadrillion Btu, increasing to 736 quadrillion Btu in the 2040 projection period (an increase of 28%), being China and India the largest energy consumers in the world. Buildings consumed about 559 trillion Btu from 1990 to 2014 (EIA, 2017). Buildings consume about 40% of the world’s primary energy consumption (International Energy Agency, Organization for Economic Co-operation and Development, 2009).

Given this scenario, mitigation measures for the effects of global warming are necessary. The insertion of clean and renewable energy in the context of energy sources is a way to reduce the consumption of fossil resources and greenhouse gas emissions. Holmes and Hacker (2007) showed that the current challenge of construction professionals is to design low-impact buildings that provide habitability for their occupants. Efficient buildings are those that, with passive strategies, low cooling, lighting, and heating demand, thus reducing consumption (Rodriguez-Ubinas et al., 2014).

Nico-Rodrigues (2015) points out that an important instrument to define housing with adequate thermal comfort conditions is to adopt guidelines that consider the relationship between climate and human beings. Recently, studies have focused on simulation of buildings thermal and energy performance through global warming effects, obtaining the energy consumption and thermal comfort conditions (Wang et al., 2017; Song and Ye, 2017).

The importance of energy efficiency measures is discussed in most articles published on the subject nowadays. Li et al., (2013) described these measures in detail, such as the ideal window opening for balancing natural light and thermal load, shading, thermal mass and ventilation. Marszal et al., (2011), emphasized the importance of efficiency, and brought issues that involve the comfort of the user, such as adequate lighting level, thermal comfort, acoustic comfort and air quality. Roaf, Fuentes, and Thomas-Rees (2014) report that traditional buildings are beginning to require adaptations in order to provide adequate levels of performance to its users in extreme weather situations.

Thus, mitigation of the effects of climate change has become public policy in many countries, and studies to adapt buildings to new climate scenarios have been conducted in many civil engineering areas (Freitas and Ambrizzi, 2012; Tateokka and Duarte, 2017). An efficient building must be designed in a suitable way so that the expense with measures implemented is not superior than the economy with energy consumption. The improvement of an efficient building is a Zero Energy Building (ZEB), thus defined by producing, by renewable energy generators, at least the same amount of energy consumed within one year (Thomas & Duff, 2013).

Torcellini et al., (2006) defined the priorities for a ZEB: the first factor was the question of energy efficiency and then, the application of renewable energy sources. There is a strong
tendency for ZEBs to be mandatory in the future. In the European Union, the deadline is from 2020 (European Parliament, 2011). In California, United States, the goal is to become mandatory for residential buildings by 2020 and for commercial buildings by 2025 (California Legislature, 2009).

**Aim**

It starts from the issue that buildings with energy generation design to meet the current consumption will suffer a delay until the end of the century, due to the increase of external temperatures caused by global warming phenomenon. Therefore, the aim of this study is to evaluate the increase in energy consumption of a zero-energy building located in the city of Cuiabá-MT, centre of South America, latitude 15°S, considering the projections of mean surface temperature increase of the A2 emission scenario of the Fourth Assessment Report (AR4) of the IPCC.

**Review**

Several studies have been carried out on the influence of global warming and climate change over the energy consumption in residences, as well as over the habitability of its occupants. Xu et al., (2012) noted, by using the IPCC guidelines in scenario A2 of greenhouse gas emissions, that the use of energy for cooling in buildings will increase about 25% from the current scenario to the 2080 scenario in California.

Wang et al., (2012) evaluated the future energy consumption of a commercial building in five Chinese cities. By the end of the century, the cities of Beijing, Shanghai and Hong Kong will increase annual cooling energy demand by 20.4%, 11.4% and 14.1%, respectively. On the other hand, the annual heating energy demand will decrease by 55.7%, 13.8% and 23.6%, respectively.

Parker (2009) and Thomas and Duffy (2013) validated the energy performance of zero-energy houses in the United States through one-year measurements, generating evidence for greater incentives for this type of construction. ZEBs are a trend, because aside from reducing energy demand, it proposes independent renewable microgeneration system, supplying buildings and reducing the need to build new power plants or generating stations. In addition to decreasing demand, the energy generation is clean, reducing levels of pollutant gases generated and released.

In the United States, buildings consume 41% of total primary energy use. About 50% of the total energy is used for heating and cooling (DOE, 2011). According to Shen and Lior (2016), ZEBs reduce the consumption of fossil fuels and greenhouse gas emissions, mitigating the effects of climate change.

The first zero energy project was developed by Esbensen and Korsgaard (1976) in Denmark, focusing on building physics through rigorous thermal insulation. The design of the solar energy system was for space heating and hot water supply, and not for all building operation, as it is currently (Esbensen & Korsgaard, 1976). Deng et al., (2011) pointed out that most projects have shortcomings and limitations, such as the fact that renewable energy technology needs to take into account the local climate, wind speed, solar incidence, lifestyle and local peculiarities, thus, it cannot be easily shared everywhere. These uncertainties call attention to the need for a specific analysis of each project.

Within this scenario, Shen and Lior (2016) used global climate models to predict the future performance of renewable energy using low-consumption residential buildings in 10 different climate zones in the USA. The results showed that buildings with current renewable
energy configurations are losing their capacity to meet zero-energy in half of the climate zones considered. It was found that generation systems for a future ZEB should be resized and reconfigured to accommodate the impacts of climate change.

Robert and Kummert (2012) stressed the importance of designing ZEBs thinking in the future and taking into account climate change, so that ZEBs can be able to obtain zero energy balance over its lifespan. In their research, also in the USA, results demonstrated that the building lost the zero energy goal in most years. The year-to-year variability of total energy use is relatively small, but the impact on excess or energy shortage relative to the zero-zero goal is significant. Therefore, the authors argue that climate-sensitive buildings, such as ZEBs, should always be designed using simulation with climatic data that take climate change into account.

Materials and Methods

Four methodological steps were outlined: characterization of the object of study, creation of future climatic data, energy simulation of the house for current and future scenarios, and lastly, the quantification of energy consumption for current and future scenarios. These steps are described below.

Case Study

The civil construction sector, within the building framework, is one of the most important agents in the solution of the Brazilian housing deficit. In 2010, this sector served about six billion households in the country and, among them, 90,000 were built in the state of Mato Grosso, region analysed in this study (IBGE, 2010). Therefore, the object of study is a single-family house with a built area of 46.69m² and a living area of 36.16m², containing one living room/kitchen (15.50m²), two bedrooms (10.40m²) and one bathroom (2.86m²) (Figure 1). The building fits into the policy to combat the Brazilian housing deficit for low-income and vulnerable population, allowing access to housing. The building fits into the policy to combat the Brazilian housing deficit for low-income and vulnerable population, allowing access to housing.

a) Floor Plan

b) Perspective view

Figure 1. Case study.
The walls are made of ceramic eight-hole hollow bricks, plastered with cement mortar on both sides. On the external face of external walls, it was designed expandable polystyrene (EPS) panels as thermal insulation. The walls’ thermal transmittance with and without EPS insulation are 2.47 and 2.50W/m²K, respectively. The roof is composed of solid concrete slab (Table 1). The absorptance ($\alpha$) of the walls and roof is 0.30. The values adopted in table 1, as well as the methodology of calculation for thermal resistance and thermal transmittance, were taken from the Brazilian standard NBR 15.220 (ABNT, 2005).

<table>
<thead>
<tr>
<th>Envelope</th>
<th>Materials</th>
<th>Thickness (cm)</th>
<th>Specific heat (c) (J/Kg.K)</th>
<th>Thermal conductivity ($\lambda$) (W/mK)</th>
<th>Density ($\rho$) (Kg/m³)</th>
<th>Thermal Resistance (m²K/W) (total envelope)</th>
<th>Thermal Transmittance(W/m²K) (total envelope)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>Mortar</td>
<td>2.00</td>
<td>1000</td>
<td>1.15</td>
<td>2000</td>
<td>1.046</td>
<td>0.956</td>
</tr>
<tr>
<td></td>
<td>Ceramic brick</td>
<td>10.00</td>
<td>920</td>
<td>0.90</td>
<td>1600</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EPS</td>
<td>3.00</td>
<td>1420</td>
<td>0.04</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mortar</td>
<td>2.00</td>
<td>1000</td>
<td>1.15</td>
<td>2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>Concrete slab</td>
<td>10.00</td>
<td>1000</td>
<td>1.75</td>
<td>2400</td>
<td>0.194</td>
<td>5.14</td>
</tr>
</tbody>
</table>

It is known that the solar orientation of a building is determinant in thermal changes and thermal performance. Therefore, in this study, it was considered the main façade facing North (0°) and eaves 1.5m wide in the North and South façades. The openings are four-leaf sliding windows of glass material (Table 2).

<table>
<thead>
<tr>
<th>Windows</th>
<th>Living room/kitchen</th>
<th>Bathrooms 1 and 2</th>
<th>Bathroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension (width x height) (m)</td>
<td>3.90 x 1.10</td>
<td>2.30 x 1.10</td>
<td>0.80 x 0.50</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>4.29</td>
<td>2.53</td>
<td>0.40</td>
</tr>
</tbody>
</table>

**Local Climate**

The region of study is the state of Mato grosso, located in the centre of South America. According to Peel et al., (2007), the Brazilian state of Mato Grosso has about 90% of its territory inserted in the Aw climate type (tropical savannah with summer rains). The other 10%, in the extreme north, is inserted in the Am climate type (tropical monsoon climate with total annual precipitation greater than 1500 mm, and driest month with less than 60 mm of precipitation) (Figure 2). As stated by Peel et. al. (2007), the Aw climate is the second most
common climate in the world, which represents 11.5% of the Earth’s land area.

The Am climate presents a dry season of short duration, with average temperature of the coldest month exceeding 18°C. The Aw climate presents a rainy season in summer, between November and April, and a dry season in winter, between May and October, with average temperature of the coldest month exceeding 18°C (Soares et al., 2015). The rainfall distribution is typically tropical, with maximum precipitation in summer and a dry winter.

Duarte (2000) states that the hot climate is significant in the state of Mato Grosso, with frequent high daily temperatures all over the year, and maximum temperatures above 40°C in the months of September and October.

**Climatic data**

For the creation of climatic data, the IPCC indicates the Morphing methodology. This methodology modifies a historical weather data set (1961-1990) of 8,760 hours in future weather projections, obtaining three representative scenarios of future climatic data. The method consists of three methodological steps, which are: i) deviation from the current scenario by adding the projected monthly variation (absolute values); ii) linear stretching of the current scenario, through projected monthly variation (relative values), and iii) combination of the first two methodological steps, described by Equations i, ii and iii (Belcher et al, 2005). It is noteworthy that the methodology is based on the fourth report and the A2 scenario of IPCC emissions.

\[
\begin{align*}
\text{i) } & x = x_0 + \Delta x_m \\
\text{ii) } & x = a_m x_0 \\
\text{iii) } & x = x_0 + \Delta x_m + a_m (x_0 - (x_0)m)
\end{align*}
\]

Equation (i)  
Equation (ii)  
Equation (iii)

\(x\): is the future weather variable;
\(x_0\): is the current weather file variable;
Δxm: is the absolute monthly anomaly according to the projection model used; 
am: is the fractionated monthly variation; 
(x0)m: is the monthly average relative to the variable x0; 
m: is the month.

For the conversion of current weather data (1961-1990) into future data, this methodology was inserted in a tool called Climate Change World File Generator (CCWordWeatherGen). This tool is available in Excel format, and enables the integration of EnergyPlus Weather Data (EPW) extension files, coupled with the Global Climate Model (MCG) “Hadley Centre Coupled Model version 3” (HadCM3) (Gordon et al., 2000, Pope; Gallani; Rowntree, 2000) (Figure 3).

Figure 3. CCWorldWeatherGen Font tool interface. Adapted from Jentsch et al., (2008)

CCWorldWeatherGen uses the term time-slice to represent future projections, as follows: 2020 (time-slice 2011-2040), 2050 (time-slice 2041-2070) and 2080 (time-slice 2071-2100). Song and Ye (2017) made their analysis in Guangdong Province, southern China, adopting the time-slices 2020s, 2050s and 2080s, as well as Indiviata and Ghisi (2016) in Brazil, and Wang et al., (2015), in the United States.

Thermal and energy simulation for current and future scenarios

For computer simulation, among various simulation software available, the Energy Plus, available from the United States Department of Energy (DOE, 2016) and recommended by ABNT 15575 (INMETRO, 2013), was adopted. With a dynamic calculation methodology, this software allows the similarity of obtained results to a real condition of thermal and energy performance of a building.

For the energy consumption simulation, it was considered lighting, equipment and occupancy (LEO) in the living room/kitchen and bedrooms, with four people in the living room/kitchen and two people in the rooms, following the timetable established by the Brazilian Technical Quality Regulation (RTQ-R) for energy efficiency level of residential buildings (Table 3).
Table 3. Schedule prescribed by the Brazilian Technical Quality Regulation (RTQ-R) for energy efficiency level of residential buildings Font. Adapted from INMETRO (2012)

<table>
<thead>
<tr>
<th>LEO</th>
<th>Weekday</th>
<th>Weekend</th>
<th>Weekday</th>
<th>Weekend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule</td>
<td>9p.m. to 8a.m.</td>
<td>9p.m. to 10 p.m.</td>
<td>2p.m. to 9p.m.</td>
<td>11a.m. to 9p.m.</td>
</tr>
<tr>
<td>Lighting</td>
<td>9p.m. to 10 p.m.</td>
<td>10p.m.</td>
<td>5p.m. to 9p.m.</td>
<td>11a.m. to 12p.m. and from 5p.m. to 9p.m.</td>
</tr>
</tbody>
</table>

The simulation was carried out in naturally ventilated condition from 9 a.m. to 8 p.m. and from 9p.m. to 8a.m., the HVAC system operates with thermostat for cooling above 24°C. It must be observed that, for the study region, it is not necessary to use a thermostat for heating due to the climate of the region.

After quantifying energy consumption, it was dimensioned power generation through photovoltaic panels, taking into account the consumption of the base period, that is, the dimensions were made under the premise of providing 100% of consumption, thus entering the ZEB category. The sizing was done by the PVsyst software, that considers local weather data and panel technical data. It were considered the losses that occurred in the electrical part of the system, the dirt that can accumulate and no shading.

In the electrical part, a loss of 3% of the total production was adopted, for the matter of dirt was considered annual maintenance, discounting 5% of the total value. The software calculates the losses in the conversion of energy that occurs in the inverters but, in general, the system had an efficiency of approximately 80%.

In order to calculate the power generated by panels, daily data of incident solar radiation were required. The values of monthly averages of the daily total solar radiation (kWh/m²/day), in all months of the year, were obtained through current and future climatic data. Using these data, as well as the house solar orientation, the PVsyst simulates the power required. These data are crossed with the power calculated by building consumption, so that it is fully supplied. It is worth mentioning that this article shows how the ZEB design will be outdated over the years when trying to meet building consumption, due to the increase of energy demand caused by climate change. However, it does not considerate photovoltaic panel deterioration, which can vary from 0.5% to 1% per year, depending on the photovoltaic panel brand.

Results

Projections for increasing annual average dry bulb temperatures are 5.65%, 11.89% and 21.51% for the 2020, 2050 and 2080 scenarios, respectively. The annual average value of the dry bulb temperature for the periods 1961-1990, 2011-2040, 2041-2070 and 2071-2100 are 26.76°C, 28.23°C, 29.90°C and 32.47°C, respectively. The highest increases occur in the months of September, May and August, with increases of 6.59°C, 6.53°C and 6.50°C, respectively (Figure 4).
The mean global horizontal radiation has a tendency to rise by 37.4% from the current scenario to the end of the century (Figure 5). The increase projection for the 2020, 2050 and 2080 scenarios are 1.21%, 2.22% and 3.74%, with values of 37.55 Wh/m², 37.93 Wh/m² and 38.79 Wh/m², respectively. The annual average value is 37.10 Wh/m² (Figure 5). In the months of November, October and March the increases are 11.65 Wh/m², 9.06 Wh/m² and 8.02 Wh/m², respectively.

The monthly average energy consumption increased by 14.28% in 2020, 21.68% in 2050 and 30.54% in 2080. It should be noted that the months of June, July, August and February are the ones with greatest increase in 2020, with values corresponding to 21.82%, 18.80%, 18.47% and 17.01%, respectively. In the 2050 and 2080 scenarios, the months of highest increase were July, June and August, with 40.80%, 37.88% and 31.25% in 2050 and 76.40%, 60.0% and 50.85% in 2080, respectively (Figure 6).
The annual energy consumption increased by 1,681kWh from the current scenario to the projection of 2080. The difference between the current scenario and the projections of 2020 and 2050 are 786kWh and 1,193kWh, representing an increase of 51.78% and 113.87%, respectively (Figure 7). It is worth noting that the use of artificial air conditioning (HVAC) directly influences the increase in energy consumption, representing 4,806kWh in 1961-1990, 5,592kWh in 2020, 5,999kWh in 2050 and 6,487kWh in 2080. The lighting system and equipment represent 698kWh of consumption in each scenario analysed.

The results show that the effects of climate change will modify cooling energy consumption of Brazilian housing. Therefore, in the future, housing strategies will be needed to minimize heat discomfort and, consequently, reduce cooling energy demand. It can be seen that when resizing photovoltaic panels, considering new radiation indices and the expected increased consumption, the power generation gap will be around 14.1% for the 2020 period, 26.3% for the 2050 period and 40.2% for the 2080 period.
Conclusion

The effects of global warming and climate change result in a potential threat to the energy behaviour of housings, directly affecting the habitability conditions, energy consumption and, when it comes to ZEBs, the zero balance that the energy generation intends to provide. Therefore, the climatic data of the place where a house is inserted is an important parameter to evaluate these conditions, and the study of the prospective behaviour becomes necessary to adapt the building.

The results of this study showed that dry bulb temperature and annual solar radiation will increase by 21.51% and 3.66%, respectively, from the current scenario to the 2080’s, consequently increasing the building energy consumption. However, the increase in power generation is not proportional to this upsurge in consumption.

In this context, this research addressed the vulnerability of zero-energy buildings (ZEBs) to the impacts of climate change on the configuration of renewable energy systems to achieve the net balance. The sizing done for current days, besides being short-lived, demonstrates the problem of energy generation that will be faced in the coming years, which demonstrates the viability and necessity of renewable energy installation with adequate dimensioning.

It is recommended, as a way to minimize the losses of this energy generation source, a projection analysis of the increase in energy consumption over the years, so that the house continues being zero energy. However, it results in greater initial investments, which may be not viable for the investor. For future studies, it is suggested to investigate other dimensions of houses, of medium and high standard, as well as other building types, such as commercial and public buildings. In addition, another factor to be investigated is the impact of climate change on ZEBs of other Brazilian climates.

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Supply Chains for Energy Efficient Housing using Mass Customisation: Adopting Japanese housing models in the UK

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Abstract: This study explores current housing supply chains to detect where processes of mass-customisation could be applied to increase the production of energy-efficient houses. Currently, most housebuilders in the property market overlook the advantages of providing energy-efficient houses. House buyers seeking sustainable options find few, or no possibilities to customise their houses in terms of energy qualities, restricted to furniture arrangements or aesthetic layouts. By contrast, Japanese house-manufacturers have realised that providing energy-efficient options (e.g. solar panels) result in an increase of sales, which is a consequence of applying a sophisticated customer-oriented marketing process called ‘mass-customisation’. A successful mass-customisation system relies on empowering customers in the design-decision-making process. Therefore, the relation of mass-customisation to energy efficiency is relevant in that it allows the users to choose the level of energy efficiency they want and can afford for their new house. This study compares the ways in which different housing companies involve customers in the design decision-making process by diagramming their supply chains. Nine housing companies were selected for this study: four housing manufacturers from Japan, three developers from the UK and two alternative models from the UK. This study concludes that there is potential for UK housebuilders to adopt mass customisation by implementing effective marketing and communication systems, but these have to be coherent with their business model and cash flow.

Keywords: Housing, Energy-efficiency, Mass-Customisation, Manufacturing, Supply-Chains

Introduction

Energy efficient houses are not impossible to achieve. There is a vast number of good examples around the UK; however, these are the result of isolated ventures and not an integral part of the housing market (Zero Carbon Hub, 2009:40–41; Guzowski, 2010; The Guardian, 2014). The UK property market is flat and limited to ‘traditional’ house types, not only in aesthetic aspects, but also in construction systems (Barlow, 1999:32; Naim et al, 2003:593; Lovell et al, 2010:458). These houses are designed for the average family and constructed to fulfil established standards (spatial, safety and energy), which limits their energy capabilities to government regulations or to the developers' criteria. The majority of house buyers in the UK are restricted to this model because opting for a bespoke (architectural) service is an expensive and time consuming alternative, perhaps even out of their reach (Shafik et al, 2006:82; Pitts, 2017:9,15).

In Japan, there is a segment of the housing market where companies manufacture houses on demand, allowing customers to choose and customise their houses in detail, even in terms of energy efficiency (Barlow et al, 2003:137–138; Davies, 2005:186–192; Yashiro, 2014:20; Aitchison, 2018:94-96). Japanese housebuilders have realised that giving customers the opportunity to choose results in greater customer satisfaction and hence higher sales (Noguchi, 2004:27). Therefore, Japanese housebuilders are using sophisticated marketing and communication processes to involve the customer in the design decision making process without modifying their production process and supply chains– which is known as ‘mass customisation’ (Davis, 1987:158; Barlow et al, 2003:138–139). Mass customisation is a sophistication of mass production models, defined as the management of supply chains...
capable of producing controlled variety of products preselected by individuals, without sacrificing the production efficiency and relative cost (Jimenez-Moreno et al, 2018).

Mass customisation relation with energy efficiency is in terms of design decision-making (Cuperus, 2003:12; Noguchi, 2003:356). Various references have highlighted that energy efficiency and passive design are linked to early decisions concerning the selection of materials (U-values), construction systems (air tightness) and suppliers of mechanical systems and renewables (Laustsen, 2008:12; Voss, 2013; Lewis, 2017). These decisions can be made after the architectural concept and plan have been settled; thus, it is true that energy efficiency is a matter of design decision making, but not mandatory during the earlier stages of the process. Therefore, it is feasible to reach high levels of energy efficiency by customising projects from pre-designed architectural plans, while the use of mass customisation strategies in the marketing of houses can allow and encourage customers to opt for energy-efficient solutions.

Housebuilders in the UK that are aware of the benefits of mass customisation are attempting to adopt Japanese housing models; however, they have struggled to merge them with their supply and cash flow chains, which are apparently not compatible (Barlow et al., 2003:143; Johnson, 2007:41; Pan et al, 2008:17). This study compares housing manufacturers from Japan with housing developers, contractors and manufacturers in the UK to visualise the points where UK companies could implement mass customisation strategies.

**Differences between the housing procurement process in Japan and the UK**

The acquisition of a house in the UK new-build market appears simple, straightforward and, on the face of it, less complex than self-building (Noble, 2017). The buying process begins when the potential home buyer applies for a mortgage— a house buyer may not require a mortgage if they have cash at hand. If successful and depending on the amount of capital approved, they can then begin their search and simply select from the stock of houses in new developments. The house— including the plot— will be handed over to the customer after concluding the bureaucratic processes related to the buying contract. Those owners who applied for mortgage will pay the house through agreed periodical payments.

![Figure 1. Typical UK purchase process for new-build. (Diagram developed by the Authors. Data collected from Noble, 2017; Barratt Homes’, 2016; the Money Advice Service, 2018)](image-url)
But, the actual housing procurement is complicated and segregated from the selling and marketing processes mainly because housing developers’ main profit comes from land speculation (Ball, 2003:908–909; DCLG, 2017:13; McKibbin, 2018). They invest heavily in the acquisition of large portions of land and bank these for a number of years until planning permission has been guaranteed and when the most profit can be made from selling the land (Jefferys, 2016).

Developers follow stable and predictable construction supply chains that involves multiple agents. They build houses (without a rush) using their own construction team or by hiring external contractors, while manufacturers and suppliers feed them with construction elements—bricks, wall/floor panels, windows, etc. They all prefer to work with predefined designs and construction systems, arguing that repeating the same processes makes the supply chain more efficient; however, it has also been criticised that this is what makes it very resistant to innovation (Goodier et al, 2005:157; Pan et al, 2007:3).

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The construction contractors and manufacturers are highly disconnected from the selling and marketing processes because they have no control over the land transactions. Housing developers for example, Barratt Homes, Persimmon Plc and Taylor Wimpey, prefer not to invest in manufacturing machinery because they consider off-site construction as an expenditure. Investing in land, however, is profitable and does not mean a depreciation of their assets (Table 1).

![Figure 2. Full procurement process. (Diagram developed by the Authors)](image)

### Table 1. Cash flow UK. (Data collected from: Barratt, Persimmon plc and Taylor Wimpey Full Year Results reports; Robertson Timber Engineering, 2018; and Robertson Group and Scotframe 2017 financial account reports available in Companies House)

<table>
<thead>
<tr>
<th>United Kingdom</th>
<th>Housebuilders / Housing developers</th>
<th>Contractor</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homes completed in 2015</td>
<td>Barratt 16,647</td>
<td>Persimmon plc 16,043</td>
<td>Taylor Wimpey 13,341</td>
</tr>
<tr>
<td>Turnover / Revenue</td>
<td>£4,650</td>
<td>£3,422</td>
<td>£3,965</td>
</tr>
<tr>
<td>Operating profits</td>
<td>£799</td>
<td>£966</td>
<td>£841</td>
</tr>
<tr>
<td>Net Cash</td>
<td>£724</td>
<td>£1,302</td>
<td>£511</td>
</tr>
<tr>
<td>TOTAL Number of plots (land) [1]</td>
<td>80,752</td>
<td>98,445</td>
<td>192,094</td>
</tr>
<tr>
<td>Acres held (2017)</td>
<td>11,737</td>
<td>16,100</td>
<td>-</td>
</tr>
<tr>
<td>Number of land approvals (per year)</td>
<td>18,497</td>
<td>17,301</td>
<td>-</td>
</tr>
<tr>
<td>Land bank years (average)</td>
<td>4</td>
<td>6 [2]</td>
<td>6</td>
</tr>
<tr>
<td>Land cash spend (annually)</td>
<td>£1 bn</td>
<td>£602 M</td>
<td>-</td>
</tr>
<tr>
<td>Investing: Purchase of property, plant and equipment (£M)</td>
<td>£4.0</td>
<td>£18</td>
<td>-</td>
</tr>
<tr>
<td>Total DEPRECIATION:</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Plant and Machinery</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Land banking is the housebuilders’ main profit activity, and thus, the defining factor in their business model (Ball, 1983: 143). To raise the value of the land, developers need to turn empty land into a habitable built environment. Therefore, housing developers merely see the construction of the ‘house’ as something that they ‘have’ to do, as a check-box or taxation. This is why their investment in land usually surpasses 20% of their revenue, while their investment in plant and equipment amounts to significantly less than 1%.

In contrast, companies such as Scotframe invest over 15% of their revenue in property, plant and equipment. In order to pay back their investments, they need to make the most of their machinery, focusing on the sale of the production capabilities of their machinery (timber frames, wall panels, insulation, windows, etc.). Companies unable to produce enough houses to fulfill their production goals have to complement their production by supplying contractors and developers with construction elements (Scotframe main business consists on selling wall panels rather than entire houses).

There are some companies, like ‘Robertson Group’, that intend to cover the whole procurement spectrum (property, constructor and manufacturer). In reality, however, their business model tends to focus on managing the interface between developers and manufacturers. They specialise in finding the most cost-effective construction solutions to the projects which they receive from their clients (developers) by finding manufacturers and subcontractors that provide competitive services or products. They will then organise the entire construction process to ensure that they remain within the previously stipulated time deadlines and costs.

Robertson Engineering, a sub-company of Robertson Group, manufacture timber wall panels for all of their residential projects unless the client requires another construction method. They avoid using timber wall panels produced by other companies but do not mind subcontracting other companies for roof trusses and other construction elements (From answered by Ben Murphy: Assistant Pre Construction Manager Robertson Group). Their reason for manufacturing their own wall panels is merely to reduce production cost and time, not to produce entire dwellings. It is clear that they are not interested in entering the housing manufacturing market as the only houses they offer (by Robertson Homes, another sub-company of Robertson Group) are constructed following the speculative model.

Scotframe sell houses on-demand to the self-build market and are therefore disconnected from land ownership (Scotframe, 2016). They produce wall panels that include windows, doors and finishing coatings bought from external suppliers, but assembled in their factories, which increases the value of their houses, or at least, their wall panels. Scotframe’s approach is similar to the Japanese business models, despite they have not been able to consolidate as a housebuilder and highly depend on their manufacturing sales.

The construction and buying processes in Japan are very different. One of the main factors that determine this difference is the land tenure and the fact that land is valued independently from the house attached to it (Barlow et al, 2001: 9; LWIF, 2017). In Japan, land is very scarce; there is a cultural sense of attachment to it and its value has been stable for the last 20 years, which makes land speculation unprofitable and unattractive. It is common for Japanese people to own a plot, reducing land transactions (Johnson, 2007: 14). Therefore, they will usually use their own land to construct a new house. As a result, 75% of the houses in the Japanese market are commissioned; in contrast to the 10% of the UK, which leaves 9 of every 10 houses to the speculative business (Barlow et al, 2001: 9).

Moreover, in Japan, there has been a constant reconstruction of housing due to high taxation on abandoned houses and empty plots, relaxed legislation on the construction of
new buildings and a constant devaluation of properties— which is mainly the result of increasing building standards in order to safeguard against fire and earthquakes (Kobayashi, 2016: 11,22,28; LWIF, 2017). Japanese houses have an average lifespan of 30 years: around half of the average life of dwellings in the UK (Brasor et al, 2014). People in Japan prefer to acquire new houses because it is as costly as buying an old one and is easier to secure mortgage and insurance (warranty) for new buildings. Consequently, Japan is building 6 times more new houses than the UK and transactions on new buildings dominate the domestic sector (Trading Economics, 2018).

Table 2. Contextual comparison related to housing.

<table>
<thead>
<tr>
<th></th>
<th>Population (millions)</th>
<th>Density (square km)</th>
<th>Housing starts per year</th>
<th>Average dwelling life</th>
<th>Resale market (percentage of houses)</th>
<th>House price compared to 20 years ago</th>
<th>New-builds over total annual domestic transactions</th>
<th>Houses Commissioned (Self-built) / Speculative (Custom Build)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>JPN</strong></td>
<td>127</td>
<td>336</td>
<td>970,000</td>
<td>33 years</td>
<td>14%</td>
<td>&lt; 0.45%</td>
<td>80%</td>
<td>75 / 25%</td>
</tr>
<tr>
<td><strong>UK</strong></td>
<td>66</td>
<td>268 / 420</td>
<td>152,400</td>
<td>60 years</td>
<td>84%</td>
<td>&gt; 200%</td>
<td>5%</td>
<td>10 / 90%</td>
</tr>
</tbody>
</table>

Japanese people are used to buying their houses directly from the housebuilders isolated from the land transaction. This has driven Japanese housing companies to develop flexible production systems to produce on demand and to the customer’s (site) needs. Thus, the selling and construction are integrated into a holistic process.

The Japanese buying process runs as follows: first, customers select a house model that best fulfils their demands from the range offered by the manufacturer— menu like. The manufacturer will then produce and deliver the house to the customer’s plot (Figure 3). As the production of the house can only start once the design has been selected, customers have the opportunity to customise their house before agreeing on the definitive design. Companies that offer more customisation can position themselves better on the market and provide higher customer satisfaction.

![Figure 3. Purchase and procurement processes for housing manufacturing in Japan. (Diagram developed by the Authors. Data adapted from Barlow et al, 2001: 18 ‘Figure 5 Typical purchase process for customised housing’)](image-url)
Japanese housebuilders have very sophisticated marketing/selling systems that clarify and accelerate the customers’ decision-making process, which facilitates the manufacturer’s management of the supply chain (Schoenwitz et al, 2013: 436). Their production lines are designed to flow consistently, allowing flexible outcomes by admitting different construction elements from different brands and suppliers (Schoenwitz et al, 2017: 82). As can be observed from the diagram below, the Sekisui Heim production line has several points where outsourced construction elements are introduced to the production line (Figure 4).

![Figure 4. Material supply to the main production line of a Sekisui Heim factory (From Bock et al, 2015: 142). All the colour bars indicate the points where materials and components from other manufacturers or other internal factories are integrated into the production line.](image)

Similar to Scotframe, Japanese manufacturers add value to their products by assembling or adding parts produced by other companies (Noguchi, 2013: 172). However, instead of limiting their offer to isolated construction elements, they focus on selling entire houses, providing the accompanying services embedded in this process, such as: financial assistance, warranty, post-sale services and maintenance (Sekisui House, 2018; Daiwa, 2017; Sekisui Chemical, 2017). This housing model is based on the manufacturers’ ability to transfer the customer’s design decisions to their supply chain by efficiently communicating each customer’s choices to their suppliers (Bock et al, 2015: 110, 111, 209). They are thus able to offer a wide range of housing models, configurations and arrangements – a key feature of mass customisation.

It cannot be disputed that there is a significant gap between house manufacturing companies in Japan and the UK. Sekisui House has 460 times more revenue, produces 9 times more houses and has 76 times more employees than Scotframe. By contrast, estate agents in the UK have a comparable revenue to Sekisui Heim and Toyota Home and even produce more detached/single houses than any Japanese company, but differ in terms of production processes and business strategies. Another significant difference between both contexts is that Japanese housebuilders are highly dependent on the use of robotics and heavy automated machinery for the production of their houses, while most houses in the UK are constructed using traditional methods (Bock et al, 2015).
Table 3. Volume comparison between companies in Japan and the UK. M=House manufacturer; PC=Pure customisation-bespoke; RE=Housing developers-real estate. (Data collected from Bock et al, 2015: 95; Barratt, Persimmon plc and Taylor Wimpey Full Year Results reports; and Scotframe, Facit Homes, Robertson Homes, and Robertson Engineering websites, accessed in May 2018)

<table>
<thead>
<tr>
<th>Company</th>
<th>Revenue (Million GBP)</th>
<th>Output* (houses per year)</th>
<th>Employees* (housing sector)</th>
<th>Number of factories</th>
<th>Construction system</th>
<th>Off-site/On-site</th>
<th>Foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPN Sekisui House [M]</td>
<td>£14,060</td>
<td>13,612</td>
<td>15,302</td>
<td>5</td>
<td>Volumetric</td>
<td>60/40 %</td>
<td>1960</td>
</tr>
<tr>
<td>JPN Daiwa House [M]</td>
<td>£24,371</td>
<td>9,286</td>
<td>4,644</td>
<td>10</td>
<td>2D pre assembled frames / Panels</td>
<td>60/40 %</td>
<td>1955</td>
</tr>
<tr>
<td>JPN Sekisui Heim [M]</td>
<td>£7,388</td>
<td>13,620</td>
<td>10,447</td>
<td>6</td>
<td>Modular Volumetric</td>
<td>80/20 %</td>
<td>1947</td>
</tr>
<tr>
<td>JPN Toyota Home [M]</td>
<td>£890</td>
<td>5,400</td>
<td>3,402</td>
<td>3</td>
<td>Volumetric / 3D steel frames</td>
<td>85/15 %</td>
<td>1975</td>
</tr>
<tr>
<td>UK Facit Homes [PC]</td>
<td>&lt; £20</td>
<td>&lt;50</td>
<td>&lt; 30</td>
<td>-</td>
<td>On-site CNC kit parts</td>
<td>0/100 %</td>
<td>2007</td>
</tr>
<tr>
<td>UK Scotframe [M]</td>
<td>£30</td>
<td>1,500</td>
<td>200</td>
<td>2</td>
<td>Panel</td>
<td>&gt;50 / - %</td>
<td>1987</td>
</tr>
<tr>
<td>UK Robertson Homes [RE]/Timber Engineering [M]</td>
<td>£565</td>
<td>-</td>
<td>1,943 / &gt; 100</td>
<td>2</td>
<td>On-site (traditional) / Panel variable</td>
<td>variable</td>
<td>1966</td>
</tr>
<tr>
<td>UK Barratt Homes [RE]</td>
<td>£4,650</td>
<td>17,395</td>
<td>6,214</td>
<td>0</td>
<td>On-site (traditional)</td>
<td>1953</td>
<td></td>
</tr>
<tr>
<td>UK Persimmon [RE]</td>
<td>£3,422</td>
<td>16,043</td>
<td>4,535</td>
<td>0</td>
<td>On-site (traditional)</td>
<td>1972</td>
<td></td>
</tr>
<tr>
<td>UK Taylor Wimpey [RE]</td>
<td>£3,965</td>
<td>13,341</td>
<td>5,183</td>
<td>0</td>
<td>On-site (traditional)</td>
<td>2007</td>
<td></td>
</tr>
</tbody>
</table>

The differences in business volume, the number of factories/employees, sophisticated methods of production and technological assets should not be a barrier to implementing mass customisation in the UK. Mass customisation housing models are more dependent on integral processes of marketing and design and place a greater focus on efficient communication with customers and suppliers than aspects of technology and production scale (Barlow et al, 2003b: 93; Ferguson et al, 2014; Blecker et al, 2004 :890, 897).

Only 19% of the new houses in Japan are constructed by the top 18 housebuilders; in the UK, the same top housebuilders produce around 50% of the housing starts per year (Barlow et al, 2001: 25). It is also common for all Japanese house manufacturers to offer a certain degree of customisation, even for those without their own factories, such as Muji, which is not included in the table (Barlow et al, 2003a: 138; Muji). However, unlike the Japanese context housebuilders in the UK consider the land as their main asset, placing them in different market sectors and calling into question the applicability of mass-customisation in the UK.

Mass customisation is a business paradigm detached from any production sector. Certain companies within other sectors (car builders, computer technology and footwear companies) claim to be capable of manufacturing their products using mass customisation (Agrawal, 2001). In theory, the adoption of mass customisation should not interfere with any business model, as it only requires adjustments within the supply chains and communication systems (Nambiar, 2009; Zhang et al, 2015: 2,7). It is worth referencing that the invention of the ‘Toyota Production System’—direct precursor of mass customisation—was a Japanese adoption of management, logistics and display organisation methods used in supermarkets in the USA mixed with locally (Japan) used manufacturing methods and technologies (Shmula, 2017; Smith, 2009: 180). This analogy could historically back-up the potential adoption of mass customisation in the UK housing context.
Potential adoption of mass customisation in the UK housing context

All housing business models in the UK have the potential of applying mass customisation, as it is simply a matter of logistics. However, it is difficult to justify why the speculative sector (developers) would want to shift their business model to invest on increasing the quality of their houses and its selling service, factors that do not represent significant profit to them (Barlow et al, 2003a: 143). They might also need to invert their actual cash flow, which would likely have a disruptive effect on their supply chains. Alternatively, there are already companies that do not have the same attachment to land and with sufficient manufacturing capacity to produce houses that could adopt mass customisation strategies without disrupting their business models. This, would certainly represent an improvement to their products and services but, more significantly, the possibility to kick start a practically unexplored market in the UK.

The following graphic (Figure 5) shows where, and how much, each company allows the customer to make/contribute decisions in the design (yellow pattern), production (blue pattern) and life cycle (magenta pattern) processes. The bottom part of the graphic represents the significance of customer involvement for mass customisation in each stage of the supply chain; superimposed by the potential of involving the customer in decisions related to energy efficiency (marked with orange bars).

### Figure 5. Relevance of customer involvement for mass customisation and energy efficiency.

- **JPN** Sekisui House [M]
- **JPN** Daito House [M]
- **JPN** Sekisui Heim [M]
- **JPN** Toyota Home [M]
- **UK** Facit Homes [PC]
- **UK** Scotframe [M]
- **UK** Robertson Homes [RE]
- **UK** Barratt Homes [RE]
- **UK** Persimmon [RE]

<table>
<thead>
<tr>
<th>Study cases: Housebuilders</th>
<th>Customer involvement in mass custom supply chains by process</th>
<th>Design</th>
<th>Production</th>
<th>Life Cycle</th>
<th>Relevance of customer involvement for Mass Customisation</th>
<th>Potential of customer involvement for Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Customer involvement in mass custom supply chains by process</td>
<td></td>
<td></td>
<td></td>
<td>- Define market - Design centered</td>
<td>- Added value to product - Production centered</td>
</tr>
<tr>
<td>JPN Sekisui House [M]</td>
<td></td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>7 high</td>
<td>7 high</td>
</tr>
<tr>
<td>JPN Daito House [M]</td>
<td></td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>6 high</td>
<td>6 high</td>
</tr>
<tr>
<td>JPN Sekisui Heim [M]</td>
<td></td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>5 high</td>
<td>5 high</td>
</tr>
<tr>
<td>JPN Toyota Home [M]</td>
<td></td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>4 high</td>
<td>4 high</td>
</tr>
<tr>
<td>UK Facit Homes [PC]</td>
<td></td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>3 high</td>
<td>3 high</td>
</tr>
<tr>
<td>UK Scotframe [M]</td>
<td></td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>2 high</td>
<td>2 high</td>
</tr>
<tr>
<td>UK Robertson Homes [RE]</td>
<td></td>
<td>None</td>
<td>None / Very low</td>
<td>None</td>
<td>1 low</td>
<td>1 low</td>
</tr>
<tr>
<td>UK Barratt Homes [RE]</td>
<td></td>
<td>None</td>
<td>None / Very low</td>
<td>None</td>
<td>1 low</td>
<td>1 low</td>
</tr>
<tr>
<td>UK Persimmon [RE]</td>
<td></td>
<td>None</td>
<td>None / Very low</td>
<td>None</td>
<td>1 low</td>
<td>1 low</td>
</tr>
</tbody>
</table>

Figure 5. Relevance of customer involvement for mass customisation and energy efficiency. M=House manufacturer; PC=Pure customisation-bespoke; RE=Housing developers-real estate. Figure adapted from Bock et al, 2015: 125 ‘Figure 5.13’ (Data collected from the same source and complemented with information gathered from visits to the factories and companies websites).
It can be observed that Japanese manufacturers involve the customer in most of the supply chain, including the life cycle of the house; while property developers in the UK merely limit their participation to processes close to the handover. All of the housing manufacturers, in both contexts, include the customer in the design process; however, the Japanese companies empower them more during the configuration of the house and selection of suppliers than the manufacturers in the UK. Sekisui House is allowing customers to select wood instead of steel as a structural material (‘Engineering system’), due to an increasing desire for wood products that contribute to the mitigation of carbon dioxide emissions through CO₂ sequestration (Bock et al, 2005: 149-157).

The menu-like sales model by itself is not equivalent to mass customisation; it is, in fact, closer to a mass-production model known as ‘pattern books’ (Davies, 2005). It is the integrated process of choosing, modifying and rearranging a design that makes mass customisation what it is (Schoenwitz et al, 2012). In addition, some Japanese companies provide bespoke design services at premium prices to expand their market scope and promote long term relations with their customers by providing high quality services after the handover of the house (Aitchison, 2018: 115-117). The ‘Re-customisation’ process is a commercial strategy used by Sekisui Heim to engage the customer in buying a new house by accepting their old house as an initial payment (Bock et al, 2005: 185-198).

The ‘Product configuration’ and ‘Selection of suppliers’ are the processes where aspects of mass customisation are as relevant to the importance of customer’s decisions as they are to energy efficiency. It is at these stages that the customer can decide the materials’ quality (U-Value), whether to add finishing treatments (air barriers), select mechanical systems and consider the installation of renewables. The proliferation and diversification of the options available to customers allow for greater levels of customisation, and therefore, the potential selection of energy efficient design strategies.

Japanese companies not only provide a wide variety of options, but also give substantial priority to ensuring that the customers are well informed on the significance of each option. Each company has multiple selling centres and showhomes around the country. There are over 400 show villages in Japan in which manufacturers construct multiple showhomes for people to compare. They also have visitor centres where customers can test and interact with their products (Davies, 2005: 186-193).

<table>
<thead>
<tr>
<th>Table 4. Customer-oriented services provided by the selected companies. NC=Not certain; LT= Lifetime.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Company</strong></td>
</tr>
<tr>
<td>JPN Sekisui House [M]</td>
</tr>
<tr>
<td>JPN Daibo House [M]</td>
</tr>
<tr>
<td>JPN Sekisui Heim [M]</td>
</tr>
<tr>
<td>JPN Toyota Home [M]</td>
</tr>
<tr>
<td>UK Facit Homes [PC]</td>
</tr>
<tr>
<td>UK Scotframe [M]</td>
</tr>
<tr>
<td>UK Robertson Homes [RE]/ Timber Engineering [M]</td>
</tr>
<tr>
<td>UK Barratt Homes [RE]</td>
</tr>
<tr>
<td>UK Persimmon [RE]</td>
</tr>
<tr>
<td>UK Taylor Wimpey [RE]</td>
</tr>
</tbody>
</table>
Japanese companies have realised that well-informed customers feel more confident in taking multiple and complex decisions, avoiding oversaturation and uncertainty during the design decision-making process. In recent years, Sekisui Heim started including PV panels as a ‘built-in’ standard instead of an option; however, the customer could still customise or complement this equipment, in terms of aesthetics (PV tiles), capacity or compatibility with other systems like thermal heating (Noguchi 2013, 169). Consequently, 78% of Sekisui Heim houses started last year included PV (Sekisui Chemical, 2017).

Scotframe and Facit Homes involve the customer in the design process, however, their scope is very limited compared to the Japanese companies: Facit Homes compromise to deliver houses with fantastic thermal capacity and airtightness, but restrict their construction elements to a type, brand and supplier (Facit-Homes); while Scotframe allow customers to decide among 7 different ways of construction in terms of insulation type, thickness and glazing quality, but only provide a short brochure (4 pages including covers) with information about the differences between the construction systems (Scotframe brochure). The adoption of mass customisation marketing strategies could allow them to increase their house sales; meaning production independence for Scotframe and a wider market scope for Facit Homes.

Conclusions

The options of energy efficient houses in the UK new-build market available to the average customer are very limited. In Japan, the use of mass customisation has resulted in an increase in the production of energy efficient houses. Housebuilders in the UK could potentially increase their production of energy efficient houses by implementing mass customisation systems in their supply chains.

Mass customisation—a manufacturing and service business paradigm—fits accordingly to the Japanese context, where houses are predominantly sold as products – in other words, without attachment to the land. By contrast, housing developers in the UK attach great value to ‘land banking’, resulting in low investments in aspects other than land assets, as this would mean a shift in their stable and profitable business model. However, there are, in fact, housebuilders in the UK that have supply chains that already allow them flexible production (including parts supplied by other manufacturers) could adopt mass customisation marketing strategies to increase their sales, meaning in the production of more energy efficient houses.

The adoption of mass customisation requires companies to administer effective communication systems to inform the suppliers about the customer’s decisions, as well as to use customer-oriented marketing techniques to guide the customer during decision-making processes. Investments in heavy or sophisticated production machinery are not entirely necessary for the adoption of mass customisation; companies in the UK could adapt their current production capacities and processes.

Acknowledgements

This study was supported by the Mexican ‘National Council of Science and Technology’ (CONACYT). The authors would like to acknowledge Professor Remo Pedreschi for his advice, Masa Noguchi for his guidance during the ‘ZEMCH 2016 Mission to Japan’ and the assistance of Ben Murphy of Robertson Group: We also appreciate the assistance of Rudi Quinn and the NRGStyle team.

References


Modelling progress in the energy efficient retrofit in the private rented sector

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Abstract: The private rented housing stock in the UK is the least energy efficient sector of the housing market. One of the tools that the government is using to attempt to address this is the Minimum Energy Efficiency Standard (MEES) which came into effect in April 2018. This requires properties to let to achieve a minimum Energy Performance Certificate efficiency rating of E – therefore dwellings that score F or G will no longer be allowed to be let out on new tenancies. The regulations are then being rolled out to existing tenancies in 2020. The government is also consulting on increasing the minimum standard to a C by 2030 or 2035.

This paper examines the housing stock in the West Midlands Combined Authority (WMCA) area and more specifically the Walsall local authority area to identify the extent to which dwellings are at risk of non-compliance with the minimum E standard. It finds that approximately 7.5% of WMCA private rented stock is currently rated band F or G and is therefore at risk of not being lettable or re-lettable by 2020. It further finds that approximately 1% of the stock is unlikely to be able to be cost effectively improved, but currently the government provides exemptions for such properties. The paper also demonstrates that most non-compliant dwellings have the potential to be improved for a cost of less than £2,500, which is the proposed cost ceiling for compliance. It shows that this level of expenditure can be very cost effective with pay back periods of less than 2 years. If the proposed minimum band C rule were to be implemented this would be very problematic for potentially as much as 40% of the rented housing stock.

Keywords: retrofit, private rented sector, energy efficiency

Introduction

The UK is committed to reducing CO₂ emissions by 80% by 2050 from a 1990 base. Approximately 29% of energy consumption is due to energy use in the home – primarily heating and hot water (BEIS, 2017a). The UK has an aging housing stock and therefore energy efficiency targets will only be achieved with extensive retrofitting of energy saving measures to the existing housing stock. It is particularly important that improvements are made to the existing housing stock as the older dwellings are more likely to be less efficient – 56% of the English stock was built before 1965 (60% in the private rented sector) – the year when the first national building regulations were introduced for new dwellings (MHCLG, 2018a).

Data show that dwellings in the private rented sector have traditionally been the least energy efficient part of the housing stock (MHCLG, 2018a). In April 2018 the Minimum Energy Efficiency Standard (MEES) was introduced. This standard states that a dwelling may not be let out if its energy efficiency rating is less than an E. This currently only covers new tenancies, but will also include existing tenancies from 2020. Going beyond this the government is also exploring the potential of a much more ambitious target of a minimum rating of C by 2030 or 2035(BEIS, 2017b)

This paper uses the private rented stock in the West Midlands Combined Authority area generally and the Walsall local authority area more specifically as a case study to examine the potential impact of the MEES minimum standard, estimate the number of affected dwellings and identify the most common range, and costings, of solutions that landlords will need to adopt in order to achieve compliance.
UK Housing Stock

The UK housing stock can be split into three types according to ownership: owner-occupied housing (63%) – the owner lives in their property; social rented (17%) – the property is owned by a registered social landlord and the tenant will often be paying under market rent; private rented sector (PRS) (20%) – the tenant is renting from a private individual or company (MHCLG, 2018a). Since 2008, when property in the UK is sold or let, it needs to have an energy performance certificate (EPC) that rates its energy efficiency in bands from A-G. From their introduction up to May 2018 over 18,000,000 EPCs have been produced for dwellings in England and Wales. As Table 1 shows, energy efficiency has generally been worst in the private rented sector.

<table>
<thead>
<tr>
<th>Energy Efficiency Rating Band</th>
<th>A/B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>owner occupied</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.0</td>
<td>3.1</td>
<td>34.3</td>
<td>43.6</td>
<td>15.9</td>
<td>3.1</td>
</tr>
<tr>
<td>2016</td>
<td>1.1</td>
<td>23.7</td>
<td>52.2</td>
<td>17.8</td>
<td>4.0</td>
<td>1.3</td>
</tr>
<tr>
<td>private rented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.3</td>
<td>6.0</td>
<td>28.0</td>
<td>40.3</td>
<td>18.4</td>
<td>6.9</td>
</tr>
<tr>
<td>2016</td>
<td>1.5</td>
<td>25.7</td>
<td>48.6</td>
<td>17.6</td>
<td>4.8</td>
<td>1.8</td>
</tr>
<tr>
<td>social rented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.0</td>
<td>13.1</td>
<td>52.6</td>
<td>28.5</td>
<td>5.0</td>
<td>0.8</td>
</tr>
<tr>
<td>2016</td>
<td>2.0</td>
<td>48.7</td>
<td>42.0</td>
<td>6.4</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>all tenures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.1</td>
<td>5.3</td>
<td>36.8</td>
<td>40.5</td>
<td>14.2</td>
<td>3.1</td>
</tr>
<tr>
<td>2016</td>
<td>1.3</td>
<td>28.4</td>
<td>49.7</td>
<td>15.8</td>
<td>3.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>

As Table 1 shows, in 2016, 6.6% of the private rented stock was still in the worst two efficiency bands – F and G, as opposed to only 1% in the social rented sector. The typical UK private tenant will be renting their home on an Assured Shorthold Tenancy (AST) – this is generally for an initial period of six months, and will then roll on month by month with the landlord required to give two months’ notice to reclaim the property. As such the AST tenant does not have rights to make changes to their home and instead is reliant on their landlord for making energy saving improvements. This leads to the lower energy efficiency in the private rented sector as the landlord will have to pay for improvements and the tenant will then benefit from lower energy bills. This is a well established phenomenon that occurs most obviously in the UK due to its short residential leases but is also observed in other European countries (Astmarsson et. al, 2013) (Hope & Boot, 2014). The UK government estimate that the average annual fuel bill for a band E property is £1,710; £2,180 for a band F property and £2,860 for a band G property. Therefore there are significant potential savings for tenants of over £1,000 per year, which clearly has the potential to affect quality of life, as these tenants are also most likely to be affected by fuel poverty (BEIS, 2018)

West Midlands Combined Authority
The West Midlands Combined Authority (WMCA) is the area covered by the seven local authorities that work with the Mayor of the West Midlands: Birmingham City Council, City of Wolverhampton Council, Coventry City Council, Dudley Metropolitan Borough Council, Sandwell Metropolitan Borough Council, Solihull Metropolitan Borough Council and Walsall Council. Table 2 shows the tenure breakdown for each local authority in the area and for England and Wales, as in the 2011 Census.

<table>
<thead>
<tr>
<th>Local Authority</th>
<th>All Households</th>
<th>Owner-occupier</th>
<th>Shared Ownership</th>
<th>Social Rent</th>
<th>Private Rent</th>
<th>Living Rent Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birmingham</td>
<td>410,736</td>
<td>226,616</td>
<td>3,940</td>
<td>99,592</td>
<td>73,405</td>
<td>7,183</td>
</tr>
<tr>
<td>Coventry</td>
<td>128,592</td>
<td>77,880</td>
<td>707</td>
<td>21,914</td>
<td>26,503</td>
<td>1,545</td>
</tr>
<tr>
<td>Dudley</td>
<td>129,867</td>
<td>89,304</td>
<td>707</td>
<td>25,719</td>
<td>12,004</td>
<td>2,133</td>
</tr>
<tr>
<td>Sandwell</td>
<td>121,498</td>
<td>69,135</td>
<td>701</td>
<td>33,439</td>
<td>15,674</td>
<td>2,549</td>
</tr>
<tr>
<td>Solihull</td>
<td>86,056</td>
<td>63,559</td>
<td>527</td>
<td>12,834</td>
<td>8,502</td>
<td>634</td>
</tr>
<tr>
<td>Walsall</td>
<td>107,822</td>
<td>67,265</td>
<td>601</td>
<td>25,967</td>
<td>12,569</td>
<td>1,420</td>
</tr>
<tr>
<td>Wolverhampton</td>
<td>102,177</td>
<td>57,812</td>
<td>419</td>
<td>28,648</td>
<td>13,455</td>
<td>1,843</td>
</tr>
<tr>
<td>Total</td>
<td>1,086,748</td>
<td>651,571</td>
<td>7,645</td>
<td>248,113</td>
<td>162,112</td>
<td>17,307</td>
</tr>
<tr>
<td>WMCA %</td>
<td>100</td>
<td>60.0</td>
<td>0.7</td>
<td>22.8</td>
<td>14.9</td>
<td>1.6</td>
</tr>
<tr>
<td>England and Wales</td>
<td>23,366,044</td>
<td>14,853,678</td>
<td>178,236</td>
<td>4,118,461</td>
<td>3,900,178</td>
<td>315,491</td>
</tr>
<tr>
<td>E&amp;W %</td>
<td>100</td>
<td>63.6</td>
<td>0.8</td>
<td>17.6</td>
<td>16.7</td>
<td>1.4</td>
</tr>
</tbody>
</table>

As can be seen the WMCA area contained just over 1,000,000 households at the 2011 census and approximately 15% are in the private rented sector. It is these dwellings that will potentially be affected by the MEES requirement.

As previously mentioned over 18,000,000 EPCs have now been produced in England and Wales and these have now been made publicly available, therefore they can be used to investigate the state of the housing stock in more detail. When an EPC is carried out the purpose for it is also identified (ie: whether it is for sale, for rent or some other purpose). Therefore it is possible to filter the data to only select those where an EPC has been carried out as one has been needed for letting purposes. This will not be a perfect match with dwellings that are currently rented out as EPCs are valid for 10 years, so some that were originally rented out may have changed to an owner occupier status and some that were bought have been bought for the purpose of being let out. In addition, as the EPC is only currently required for a new tenancy there may be some dwellings that are rented out that do not have an EPC as they have had the same tenant since 2008 – it is not known how many such tenancies there may be, the English Housing Survey suggests that the average private tenancy is 4 years (MHCLG, 2018a). In addition there may be some dwellings where the landlord is in breach of the requirement to provide an EPC. For dwellings where there is no EPC due to the length of the tenancy, or the landlord is non-compliant, it may be reasonable to assume that these dwellings maybe less energy efficient than those where there is more awareness. Conversely, some of those with an EPC for purchase that have been bought for renting out may have had subsequent improvements that have not been captured by a new EPC as purchase is widely recognised as a trigger for improving a dwelling (EST, 2011). Despite
those caveats, as Table 3 shows approximately 58% of the PRS dwellings in the WMCA area have an EPC and that is a large enough sample to assume it is a good representation of the entire stock. Table 3 shows the headline information for each WMCA local authority for F and G ratings of PRS dwellings.

Table 3. % PRS Dwellings in EPC Bands F & G by Local Authority (EPC Register, 2018)

<table>
<thead>
<tr>
<th>Local Authority</th>
<th>PRS Households</th>
<th>PRS EPCs</th>
<th>% Coverage</th>
<th>Current F&amp;G</th>
<th>F&amp;G %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birmingham</td>
<td>73,405</td>
<td>42,437</td>
<td>57.8</td>
<td>3,129</td>
<td>7.4</td>
</tr>
<tr>
<td>Coventry</td>
<td>26,503</td>
<td>13,722</td>
<td>51.8</td>
<td>831</td>
<td>6.1</td>
</tr>
<tr>
<td>Dudley</td>
<td>12,004</td>
<td>7,252</td>
<td>60.4</td>
<td>578</td>
<td>8.0</td>
</tr>
<tr>
<td>Sandwell</td>
<td>15,674</td>
<td>10,072</td>
<td>64.3</td>
<td>711</td>
<td>7.1</td>
</tr>
<tr>
<td>Solihull</td>
<td>8,502</td>
<td>5,683</td>
<td>66.8</td>
<td>424</td>
<td>7.5</td>
</tr>
<tr>
<td>Walsall</td>
<td>12,569</td>
<td>6,543</td>
<td>52.1</td>
<td>550</td>
<td>8.4</td>
</tr>
<tr>
<td>Wolverhampton</td>
<td>13,455</td>
<td>8,628</td>
<td>64.1</td>
<td>820</td>
<td>9.5</td>
</tr>
<tr>
<td>Total</td>
<td>162,112</td>
<td>94,337</td>
<td>58.2</td>
<td>7,043</td>
<td>7.5</td>
</tr>
</tbody>
</table>

The English Housing Survey estimate is that 6.6% of the English PRS stock is rated F or G. Table 3 suggests that it is 7.5% on average across the WMCA local authorities. From the table it can also be estimated that there are approximately 12,000 dwellings in the WMCA area that are affected by the MEES minimum standard and these dwellings will need to be improved if they are to be let out on new leases now or on existing leases come 2020. The current social housing waiting list across the WMCA stands at 56,000 (MHCLG, 2018b), so if these 12,000 dwellings were to be withdrawn from the PRS sector that would add extra pressure to the social rented sector.

EPCs not only provide a current rating but also provide a set of recommended improvements that can be made to improve the energy efficiency and reduce the energy costs of a dwelling and also provide a theoretical new rating after the improvement measures have been carried out. It is possible that some dwellings will not be able to achieve an E efficiency rating even after carrying out all the recommended improvements and Table 4 identifies the extent of this problem:

Table 4. Percent PRS Dwellings trapped in EPC Bands F & G by Local Authority (EPC Register, 2018)

<table>
<thead>
<tr>
<th>Local Authority</th>
<th>Current F&amp;G</th>
<th>Potential F&amp;G</th>
<th>% PRS Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birmingham</td>
<td>3,129</td>
<td>730</td>
<td>1.0</td>
</tr>
<tr>
<td>Coventry</td>
<td>831</td>
<td>249</td>
<td>0.9</td>
</tr>
<tr>
<td>Dudley</td>
<td>578</td>
<td>114</td>
<td>0.9</td>
</tr>
<tr>
<td>Sandwell</td>
<td>711</td>
<td>163</td>
<td>1.0</td>
</tr>
<tr>
<td>Solihull</td>
<td>424</td>
<td>77</td>
<td>0.9</td>
</tr>
<tr>
<td>Walsall</td>
<td>550</td>
<td>124</td>
<td>1.0</td>
</tr>
<tr>
<td>Wolverhampton</td>
<td>820</td>
<td>167</td>
<td>1.2</td>
</tr>
<tr>
<td>Total</td>
<td>7,043</td>
<td>1,624</td>
<td>1.0</td>
</tr>
</tbody>
</table>

This shows that approximately 1% of the West Midlands stock will not practically be improvable to at least an E standard. Whilst there is an exemption in place for such dwellings
it can be anticipated that over the longer period these dwellings are likely to be lost to the private rented sector.

**Energy Saving Measures**

There are broadly three ways in which the energy efficiency of these dwellings can be improved: improve the thermal efficiency of the building envelope (insulation); improve the energy efficiency of the heating system (improved controls or new efficient systems); generating energy on site (e.g.: PV). When an EPC is produced it uses the standardised Reduced data Standard Assessment Procedure (RdSAP) (BRE, 2017). For RdSAP an assessor measures a dwelling to calculate gross internal area (GIA), floor heights and exposed perimeter, and records the relevant fabric details (roof, wall, floor construction and assumed insulation), heating system and controls; lighting. RdSAP software then calculates energy demand and related emissions based on standardised occupancy and heating patterns and has a standardised set of improvements, as detailed in Table 5, from which the software will chose according to a set of heuristics (e.g.: top up loft insulation to 270mm if currently less than 150mm depth).

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Energy use</th>
<th>Energy generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loft insulation</td>
<td>Cylinder thermostat</td>
<td>Solar water heating</td>
</tr>
<tr>
<td>Flat roof insulation</td>
<td>Low energy lights</td>
<td>Photovoltaics</td>
</tr>
<tr>
<td>Room in roof insulation</td>
<td>Heating controls</td>
<td>Wind turbine</td>
</tr>
<tr>
<td>Cavity wall insulation</td>
<td>Biomass boiler</td>
<td></td>
</tr>
<tr>
<td>Solid wall insulation</td>
<td>Air/ground source heat pump</td>
<td></td>
</tr>
<tr>
<td>Floor insulation</td>
<td>Micro-CHP</td>
<td></td>
</tr>
<tr>
<td>Cylinder insulation</td>
<td>Upgrade boiler</td>
<td></td>
</tr>
<tr>
<td>Draught proofing</td>
<td>Flue gas heat recovery</td>
<td></td>
</tr>
<tr>
<td>Double glazed windows</td>
<td>Storage heaters</td>
<td></td>
</tr>
<tr>
<td>Insulate doors</td>
<td>Waste water heat recovery</td>
<td></td>
</tr>
</tbody>
</table>

This is an extensive set of measures designed to cover most situations of the varied housing stock of the UK. Potentially, having to install some of the more expensive measures on this list could easily see a landlord having to spend tens of thousands of pounds per dwelling on improvements. In 2017 the government consulted on the regulations and proposed a cost cap of £2,500 – the response to the consultation exercise is still awaited, but potentially this cap would provide an exemption to many landlords (BEIS, 2018). Under the proposed cap, if a landlord can demonstrate that the improvements required to achieve the standard would cost more than £2,500 then they could apply for an exemption from having to comply with the minimum standard. Where an EPC provides recommendations for improvements it also provides indicative costs of carrying out the improvement. Table 6 presents the improvement measures based on the mid-point of the EPC cost estimate:

<table>
<thead>
<tr>
<th></th>
<th>Low cost (£&lt;500)</th>
<th>Medium cost (£500-£2,500)</th>
<th>High cost (£&gt;£2,500)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>£5 each</td>
<td>Flue gas £650</td>
<td>Upgrade boiler £2,600</td>
</tr>
<tr>
<td>Insulate cylinder</td>
<td>£22</td>
<td>Waste water £655</td>
<td>Floor £3,000</td>
</tr>
</tbody>
</table>
Draught proofing £100  Cavity wall £1,000  Glazing £4,900  
Loft insulation £225  Flat roof £1,175  Solar water £5,000  
Cylinder thermostat £300  Room in roof £2,100  Micro-CHP £5,500  
Heating controls £400  Heat pump £6,500  Heat pump £6,500  
Insulate doors £500 each  Insulate solid wall £9,000  
Storage heater £500 each  

As can be seen, almost half of the recommended measures are too expensive to install if the proposed £2,500 cap is applied and all the dwellings requiring such a measure would therefore be exempt from the regulations in their current form. Before needing to analyse individual dwellings to identify whether they are likely to need to comply or not it is worthwhile comparing the common features of dwellings with different energy efficiency ratings.

Walsall Local Authority Housing Stock

In order to provide more detailed analysis, the Walsall local authority has been chosen from the constituent members of the WMCA as it has a good range of building densities. Walsall has 6,543 rental property EPCs available in the EPC data. Table 7 gives a breakdown of some of the main options for heating system, wall type and roof insulation in the different bands for the Walsall local authority in the WMCA:

<table>
<thead>
<tr>
<th>Table 7. Percent per EPC band of PRS dwellings with a particular feature (EPC Register, 2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
</tr>
<tr>
<td>Mains gas</td>
</tr>
<tr>
<td>Community</td>
</tr>
<tr>
<td>Electric</td>
</tr>
<tr>
<td>Roof</td>
</tr>
<tr>
<td>200mm+ insulation</td>
</tr>
<tr>
<td>Dwelling above</td>
</tr>
<tr>
<td>Wall</td>
</tr>
<tr>
<td>Insulated cavity</td>
</tr>
<tr>
<td>Uninsulated cavity</td>
</tr>
<tr>
<td>Solid brick</td>
</tr>
<tr>
<td>Insulated solid brick</td>
</tr>
<tr>
<td>Built form</td>
</tr>
<tr>
<td>Detached House</td>
</tr>
<tr>
<td>Semi-detached house</td>
</tr>
<tr>
<td>Terraced house</td>
</tr>
<tr>
<td>Houses/Bungalows</td>
</tr>
<tr>
<td>Detached flat</td>
</tr>
<tr>
<td>Semi-detached flat</td>
</tr>
<tr>
<td>Terraced flat</td>
</tr>
<tr>
<td>Flats</td>
</tr>
</tbody>
</table>
There are some quite stark differences in moving from band B down to G (there were no A rated PRS dwellings in the Walsall sample). Nationally over 80% of dwellings are heated by mains gas, which is a reasonably efficient option. However, when it comes to bands F and G they are mostly heated by electricity – a mixture of individual room heaters and storage heaters. The EPC efficiency rating is price based and a kWh of electricity is currently estimated to cost 16.12p on the standard tariff or 18.97p peak and 7.06p off-peak for Economy 7, as opposed to 4.01p per kWh from gas (BRE, 2018). This therefore clearly explains why it is difficult for electrically heated dwellings to achieve high energy efficiency ratings.

Again there is a clear difference when it comes to insulating the roof. For the band B dwellings 66% are showing as having a dwelling above – from an energy efficiency perspective this is ideal as it is assumed that the dwelling above is being heated in the same way and therefore there is no heat loss to the dwelling above – this corresponds with the built form data which show that 88% of the band B dwellings are flats. Once the flats with a dwelling above are discounted 60% of the remaining band B dwellings have at least 200mm loft insulation vs 4.5% of dwellings with a roof in band G.

A similar pattern can be observed with the walls. The majority of domestic walls in the UK are either cavity walls or solid brick, there are also some timber frames and system builds, although these are generally amongst the newer stock that is more likely to have been built to achieve minimum energy standards in the building regulations. Cavity walls built in the last 20 years are expected to have been built with insulation built in to the cavity, older ones could have been retrofitted and the EPC inspector will look for signs of that when carrying out the inspection. The solid brick wall – as its name suggests – does not have a cavity but does have the option of internal or external insulation being retrofitted. Less than 1% of the band B stock has an unfilled cavity; whilst over 6% of the band B stock has a solid brick wall only a single dwelling showed in the Walsall data as having uninsulated solid brick walls. At the other end of the scale, only 18% of the band G dwellings have an insulated cavity, and 58% are solid brick walls, with only 4% of those insulated.

Finally, Table 7 provides built form data on the Walsall PRS dwellings. These have been separated out to show houses and bungalows and whether they are detached, semi-detached or terraced, and flats and maisonettes and whether they are detached, semi-detached or terraced. Here, there is a marked difference between the band B dwellings and the rest – 14.4% of flats achieve a band B rating but only 0.8% of the houses and bungalows. As discussed earlier – a lot of this is due to having another dwelling above, some will also benefit from having a dwelling below. In addition many will have a sheltered wall – eg: part of a flat will share a wall with communal space in a building – communal hallways, stairs etc – which will generally be warmer than if the walls of the flat are directly exposed to the outside of the building. A large proportion of band C’s stock is still in the form of flats, whereas bands D and E are more similar to the national average of 21% of the dwelling stock being flats. Interestingly bands F and G are again mostly made up of flats as opposed to houses and bungalows. Therefore the band F and G flats have a theoretical potential to be improved to a similar standard to the band B dwellings as they will have some of the built form advantages of sharing some of their external envelope with another flat or with a sheltered communal space.
It can be seen from the analysis of the data that the band F and G dwellings are mostly electrically heated and mostly have low levels of loft insulation and predominantly have uninsulated walls. If the £2,500 cost cap is to be implemented then many of these properties will be able to apply for an exemption. Changing the heating system is too expensive an option, except for moving to electric storage heating. With the estimated cost of £500 per heater, this is only going to be an option for smaller dwellings without too many rooms, an analysis of the data suggests that this could be an appropriate measure for 35% of the band F and G PRS stock in the Walsall local authority area.

**Individual dwelling analysis**

From the bulk data it is not possible to determine the effectiveness of any individual set of measures, only of installing all the measures recommended for that particular dwelling. However, it is possible to estimate the impact individual measures will have by manually downloading complete EPCs for individual dwellings, below are two extracts from the EPC for one of the PRS dwellings in Walsall showing the list of recommended improvements and their impact on the energy efficiency rating.

### Table: Summary of this home’s energy performance related features

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>Solid brick, as built, no insulation (assumed)</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Roof</td>
<td>Pitched, no insulation</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Floor</td>
<td>Suspended, no insulation (assumed)</td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>Single glazed</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Main heating</td>
<td>Room heaters, electric</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Main heating controls</td>
<td>Appliance thermostats</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Secondary heating</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Hot water</td>
<td>Electric immersion, standard tariff</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Lighting</td>
<td>Low energy lighting in 75% of fixed outlets</td>
<td>★★★★★</td>
</tr>
</tbody>
</table>

**Figure 1. Recommendations section from a Walsall PRS dwelling’s EPC (Stroma, 2014).**

<table>
<thead>
<tr>
<th>Recommended measures</th>
<th>Indicative cost</th>
<th>Typical savings per year</th>
<th>Rating after improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase loft insulation to 270 mm</td>
<td>£100 - £350</td>
<td>£425</td>
<td>G14</td>
</tr>
<tr>
<td>Internal or external wall insulation</td>
<td>£4,000 - £14,000</td>
<td>£636</td>
<td>F32</td>
</tr>
<tr>
<td>Floor Insulation</td>
<td>£800 - £1,200</td>
<td>£122</td>
<td>F36</td>
</tr>
<tr>
<td>Draught proofing</td>
<td>£80 - £120</td>
<td>£65</td>
<td>F38</td>
</tr>
<tr>
<td>Fan assisted storage heaters and dual immersion cylinder</td>
<td>£1200 - £1600</td>
<td>£656</td>
<td>D68</td>
</tr>
<tr>
<td>Solar water heating</td>
<td>£4,000 - £6,000</td>
<td>£38</td>
<td>C69</td>
</tr>
<tr>
<td>Replace single glazed windows with low-E double glazed windows</td>
<td>£3,300 - £6,500</td>
<td>£124</td>
<td>C75</td>
</tr>
<tr>
<td>Solar photovoltaic panels, 2.5 kWp</td>
<td>£9,000 - £14,000</td>
<td>£253</td>
<td>B86</td>
</tr>
</tbody>
</table>

**Figure 2. Summary description section from a Walsall PRS dwelling’s EPC (Stroma, 2014).**
This dwelling has a current rating of G(4) and does not have mains gas available. The thresholds for the bandings are G: < 20; F: 21-38; E: 39-54; D: 55-68; C: 69-80; B: 81-91; A 92+. The numerical score is based on an energy cost per square metre, the relationship is linear at low costs (high EPC rating) and logarithmic at high costs (low EPC rating), and is designed so that the property that scores 100 should have no bills for heating, hot water and lighting (BRE, 2014). As the relationship is not exactly linear it is not possible to get a 100% accurate estimate of the improvement by simply changing the order in which improvements are carried out from those in Figure 1, although it can provide a reasonable approximation. It is also useful to identify the options that would be plausible within the proposed £2,500 limit and make a reasoned estimate as to the end result. It can be seen that the largest impact would be from installing storage heating and a dual immersion cylinder (30 points), taking the mid-price point this would be a cost of £1,400. This could be coupled with £225 on topping up the loft insulation (10 points). The two remaining measures within the price range are the floor insulation with an estimated cost of £1,000 and draught proofing at £100. In Figure 1 floor insulation improves the score by 4 points and draught proofing by 2. Given that this property started with a score of 4 and needs to reach 39 to reach the E band, it is likely that installing the fan assisted storage heater, dual immersion cylinder and loft insulation would achieve it with a spend of approximately £1,600 adding an extra £100 for the draught proofing and this property should expect to achieve a score in the mid-40s and therefore an E rating. Whilst the extra expense on the floor insulation would have a slightly larger impact it is not very cost effective as it costs ten times as much and only provides twice as much an improvement. Also floor insulation is a very disruptive technology to install as existing floors must be lifted and there is consequently significant disruption for a tenant, and the need to make good after installation, potentially leading to a need for replacement carpeting.

It is worth looking at this from a cost effectiveness perspective. For the three chosen measures the EPC estimates costs of at the worst £2,070 and estimated energy bill savings of £1,146 giving a theoretical rate of return of 55%, or a payback period 1 year 10 months. A Rightmove (2018) property search found a similar property in a neighbouring street being advertised for a rent of £595 per month – interestingly the advertised property has an F band and therefore should not be available for rent unless the landlord has applied for an exemption – an expenditure of around £50 would see this particular dwelling comply (low energy lighting and a hot water cylinder jacket). Nevertheless, a theoretical saving of over £1,000 per year on energy bills is potentially very significant for a tenant paying just over £7,000 per year rent. The saving has been described as theoretical for several reasons: firstly this exact figure would only be achieved for the theoretical household that operates its heating and occupancy patterns in the same way as the standard RdSAP assumption; secondly, there is the ‘rebound effect’ whereby the tenant is likely to use some of the savings to improve their quality of life – heat the house more, use more hot water etc. (Wrigley & Crawford, 2017); thirdly, evidence is beginning to exist that suggests some willingness to pay a higher rent for a more efficient property – ie: some of the saving would get passed on to the landlord rather than the tenant gaining all the benefit (Carroll, Aravena, Denny, 2016).

Conclusions

The results demonstrate that it is quite possible to improve many band F and G properties to a band E within the proposed £2,500 cost cap, therefore there is good potential for dwellings to be improved to achieve the current minimum E standard. It is also worth considering the proposed minimum C rating by 2030 or 2035. This is a much more ambitious target and 68%
of the PRS dwellings in the Walsall local authority would be affected by such a requirement. It would also affect 54% of the social housing in the area. If this many dwellings could no longer be let, it would be very disruptive for the markets and it is not at all clear how this could be managed. As the data in Table 7 show achieving band C is generally possible for cavity wall dwellings with mains gas – where the cavity is filled, a new gas boiler is installed and the loft insulation is increased to 300mm it is likely to achieve a band C. That therefore leaves the issue of the 'hard-to-treat' homes, which has been estimated as being as much as 40% of the UK housing stock (Rodrigues, et al., 2018). The hard-to-treat homes are generally those with solid walls and no access to mains gas, or are in large blocks of flats where the agreement of all leaseholders is needed for any changes to be made. Certainly, the evidence suggests that a blanket ban on the letting of band D and E properties would not currently be practical, but landlords should be aware that it is a potential future issue that may need to be addressed.

In conclusion it is possible for the majority of affected dwellings to be improved to a band E. This will have benefits primarily for tenants in the form of lower bills, but is also potentially starting to have an impact for landlords as evidence is starting to grow that tenants are becoming more prepared to pay a higher rent for a more efficient property with lower utility bills. This has the potential to become a virtuous circle that will encourage landlords to spend to improve their rented properties, although this is likely to need government support to be encouraged and promoted. The potential minimum band C rating is a much more challenging target that will require greater government intervention and will need successful engagement with landlords to determine appropriate solutions. As has been shown, EPCs provide a potentially long list of recommended improvements and some of these may not currently be practical, however prices of innovative technologies may fall as they become more widely adopted in the future (Lee, et al., 2014). Therefore there is the need to produce an effective decision making tool to aid landlords in selecting the most appropriate and cost-effective measures to improve the energy efficiency of their dwellings.

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The Role of Egyptian Residential Buildings Energy Code in Enhancing Sustainable Development in Egypt: Evaluation of Nine Years of Practice

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Abstract: Achieving sustainable development in general, and in emerging countries in particular is a challenging process that requires the contribution of various governmental, institutional, and individual entities. The role of architectural design is essential in this process as it is considered as one of the earliest steps on the road to sustainability. Residential buildings sector is responsible for 40% of energy consumption in Egypt. Egyptian Residential Buildings Energy Code (ERBEC) was established in 2006 to address the minimum requirements of energy efficient building in Egypt. This study aims to evaluate the nine years of practice of the ERBEC, based on a structured questionnaire among the architectural firms in Egypt. A case study of fifty two architectural firms in Cairo were selected and categorized according to their sizes; large-scale, medium-scale, and small-scale. A questionnaire was designed and sent to the firms via email, and personal meetings with some firms’ representatives took place. The results of the study revealed that only little percentage of the large-scale firms have clear strategies for the use of the ERBEC in their design process; however, the application is limited to certain projects, or according to the client request. On the other hand, the percentage of small-scale firms is much less, and it is almost absent in the medium-scale ones. This demonstrates the urgent need of enhancing the awareness of the Egyptian architectural design community of the great importance of addressing the ERBEC starting from the early stages of the building design.

Keywords: Architectural Firms, Egyptian Residential Buildings Energy Code, Energy Efficiency, Sustainable Development in Egypt.

Introduction

Achieving affluent human environment with the less demand on resources such as materials and energy, is one of sustainable development aims, which consists of three dimensions, namely economical, social and environmental. Therefore energy has a crucial effect on these factors such as increasing demand on energy due to rapidly population growth and their spending in addition to fossil fuel production and consumption impact on the environment, (Johansson, 2002) (Annual report, 2015).

In developing countries electricity is the predominant consumer in energy sources, therefore energy policies have to consider efficiency and conservation issues (Martínez, 2015) particularly the last five decades (Baniassadi, A., et al, 2018) moreover it is one of major aims of the Egyptian sustainable development vision 2030. Shaikh et. Al, (2016), mentioned that reducing energy consumption in building sector decreases the dilemma of energy resources deficiency, while residential sector is responsible for more than 27% of global electricity consumption (IEA, 2017).

In a local context 99% of households in Egypt connected to the electricity system, this in addition to socio-economic development led to significant increasing on electricity demand.
in recent years (Razavi, 2012), sales ratio of air conditioner in Egypt the past decade could be taken as an evidence where it increased about 14 times where reached 54000 units in 1996 and 766000 in 2010 (Attia et. al., 2012) and (Attia and Evrard, 2013) what expected to increase under the impact of global warming, thus there is a necessity for codes to provide frameworks and guidelines to adapt the relation between building and its energy consumption and sustainability in general. In this context Egyptian government established energy codes as one of its strategies to develop energy sector.

Housing and Building National Research Center (HBRC) established the Egyptian Residential Buildings Energy Codes (ERBEC) in 2006 to achieve the minimum requirements to improve energy efficiency in existing and new residential buildings for each climate zone in Egypt (HBRC, 2008), Hanna (2004, 2011 and 2015) investigated the development and procedures criteria of ERBEC, however the research team argue that it misses accuracy because each climatic region covered wide area which has a vast various between microclimate and macroclimate. Furthermore, (Mahdy and Nikolopoulou, 2014) enhances this argument where they suggested a development achieved much better results than the ERBEC, Nevertheless it should be applied during design or retrofitting processes in Architecture, Engineering and Construction sector, what reflected the importance of designers’ role to contribute in solving this problem.

Several studies investigated the awareness level of codes and rating systems which include related issues to the energy. (Shamseldin, 2015) pointed out to that about 80% of construction makers in Egypt do not know the existence of a local rating system, namely Green Pyramid Rating System (GPRS) which provides environmental assessment method of buildings, and she concluded that the the government is responsible of increasing local building sector awareness, to encourage professional stakeholders to apply it and to enforce it within the building permits, as well as policy makers have the ability to increases efficiency of energy codes implementation systems (Evans et al, 2017).

On the contrary, (Khodeir and Nessim, 2017) highlighted that large architectural firms in Egypt are recently being oriented towards the adoption of Building Information Modelling and Building Energy Modelling in order to conserve energy, however their result employed among employees of 20 firms was not limited to AEC sector only, what could be considered in their findings. In the same context Mohamadin et al (2018) mentioned that uses of environmental software among architectural firms are increasing in terms of energy and competitively aspects.

From the above literature a contradiction blowed up about environmental awareness in AEC sector, therefore there is a need to investigate to what extent designers in AEC sector in Egypt apply the code limitations during design residential projects of any level, which are classified economically according to Egyptian Housing Minister Decree no.37 in 1977 into four categories based on area, firstly economical, which shouldn't exceed 60 m2, secondly middle from 50 m2 to 90 m2, thirdly upper-middle from 75 m2 to 125 m2 and finally high which is higher than 125 m2, specially several codes and systems are spreading in Egypt which aims design or construction processes either well-known global systems such as LEED, or local such as GPRS and TARSHEED which developed recently (http://www.tar sheed-eg.com).

In the context of energy issues awareness, authors argue that there is a factor affects ERBEC implementations in practice in Egypt. For instance, postgraduate education in Cairo University could be taken as an indicator where registered post graduate candidates in Environmental Design program - under Architecture program- accounted by the large amount
between 2011-2016 this argument popped up based on a personal experience of one of the authors, where ERBEC is one of core courses of the program.

Given the above, several factors should be considered during the investigation, namely residential projects types, postgraduate education, in addition to investigate designers’ point of view about codes implementation responsibility and obstacles.

Research Design and Methodology

A quantitative research method was employed through a survey among architectural firms (respondents) in Egypt. A structured (close-ended) questionnaire was designed by the research team for this purpose, and it was distributed in three stages between October and November 2017, and between March and May 2018. The first stage was a pilot test stage applied to real respondents in order to investigate responses to questions and to verify if there are incomprehensible terms or ambiguities, and the second stage was the full-scale study stage.

In the pre-testing stage, six respondents were contacted through direct phone call followed by e-mails to complete the questionnaire, these firms were as following; one well-known large-scale firm, one medium-scale firms and four small-scale firms, and it was then modified and the problems of unclear wording, conflict on understanding and questionnaire length were corrected. Then in the full-scale study, the questionnaire was distributed through the online platform (Google Forms) on a number of fifty two firms -including the pre-testing samples- practicing architectural design in Egypt. Where firms’ size classified according to the American Institute of Architects (AIA); where it has been frequently measured in terms of employment numbers where it divided into three size where small firms as 1-9 employees, medium firms from 10-49 and large firms as 50 or more.

The selection criteria of the architectural firms included in this study was based on several aspects as follows; firstly all the study group should be of licensed firms that have a professional working practice in the Egyptian market not less than five years, secondly leaded by registered architects and located in Greater Cairo which corrected later to be Egypt due to pre-testing stage’s feedback. Those firms either provide architectural service as standalone architectural firms, or design department in AEC firms.

The Investigation

Firms’ representatives (owners, principals and design engineers) were asked to fill out the questionnaire that is consisted of seven questions, which is divided into two categories, firstly from question 1 to 4 to verify firms' characteristics, namely; firm size, employees' academic qualifications, and the economic level of their residential projects and client, secondly questions from 5 to 7, to verify how often they make ERBEC part of their design process, what are the factors that led them to decide not to be guided by the ERBEC, and who is the responsible to apply the code.

Firms characteristics

Patterns throughout the firms cohorts of the study group were looked at and trends were outlined. First set of questions, the respondents accounted for fifty-two firms; 24 small firms(SF), 9 medium firms (MF) and 19 large firms (LF), the academic qualifications the results
show that 63% of respondents have a post graduate employees, as well as the majority of LF while MF and SF are equally as shown in figure 1.

![Figure 1. Academic qualifications in different firms' size](image1)

On the other hand, the majority of samples work in private sector projects accounted for 93% while 7% work in governmental projects. For economic level of the residential projects investigation, the result of multiple choices question shows that high-income projects represented the significant amount accounted for 44 responses followed by upper-middle, middle and low income housing accounted by 15, 11 and 2 respectively, as shown in figure 2.

![Figure 2. Housing projects economical levels : respondents scope of work](image2)

**ERBEC Implementation**

Study population was asked to state to what extent they apply ERBEC in their design process in any housing projects. The responses showed that 40% of the study population have never used the code before. On the other side, only 8% very often used the code, while 35% and 17% used the code sometimes and rarely respectively.
In the same context, figure 4 shows the relation between firm size and code implementation, firstly, in LF about 47% sometimes follows the code, while 16% didn’t use the code, then 26% and 11% use it rarely and very often respectively. On the other side SF result shows that 50% never use the code before, followed by 33% sometimes then 13% and applied the code rarely and 4% very often. While in MF the majority -67%- never use the code before while the rest answers are equally by 11% for each.

Regarding the relation between the residential projects economic level and the implementation of ERBEC as depicted in figure 5, and from the shown 60% participants in figure 3 that are apply ERBEC, the result illustrates that the very-often-respondents applied codes in high-income and upper-middle-income housing projects, while the majority of sometimes-respondent group applied the code in High-Income projects then upper-middle decreased by half, followed by middle-income and low-income respectively, finally the majority of rarely-respondent group applied the code in both high and upper-middle incomes projects.
To investigate the respondents’ point of view about the aspects which led them not to be guided by the code and the obstacles see questionnaire in Annex 1. The choices designed not only to cover both extremes of answers but also to check the reliability of respondents, for instance, several responses were excluded due to conflicts in answer such as "I sometimes use the code" but in following response "I have never heard about it".

Overall, as shown in Figure 6. And annex 1, the answers could be categorized in two categories; first group, those whom know the code requirements, where 38% from respondents mentioned it is unimportant in the real experience due to market demands, second respondents category accounts by 13% didn’t try to follow it or to provide the idea to the client, then 8% referred to clients' responsibility to refuse the code, then 8% mentioned they used another codes, and finally only 2% stated they already apply ERBEC.

Second category those whom did not hear about the code, 17% mentioned that they have never heard about ERBEC before, and followed by 13% whom will take it into their considerations later.

In the same context, figure 7 depicts the relation between firm size and ERBEC using/non-using.
The result shows that in LF the large amount account by 47% emphasized on ERBEC not in market's interested area, and 11% use another codes and 16% through the responsibility on client, while 26% never hear about it. On the other hand, SF recorded similar percentage to LF with quite difference that 18% of samples did not try. Eventually MF where 33% did not try to apply the code, while there is not any respondents put the responsibility on the client, and 22% mentioned they never heard about the code, finally the following answers distributed equally by average 11%.

On the other side, to investigate respondents' point of view about who is the responsible to apply the code, the result shows that 42% mentioned policy makers then by owner and architects by 33% and 25% respectively, as shown in the figure 8. This ordering is similar to LF and SF, while MF proceeded the responsibility as following; policy makers, architects and owners, as shown in figure 9.
Conclusion

The study confirms a number of the assumptions that are set previously in this paper; that only little percentage of the large-scale firms have clear strategies for the use of the ERBEC in their design process, however the application is limited to certain projects, or according to the client request. On the other hand, the percentage of medium-scale firms is much less, and it is almost absent in the small-scale ones. This shows a correlation between the firm size and the application of the ERBEC. Although large-scale firms have the highest positive responses, the number of firms in terms of implementation of ERBEC is still few where positive responses of large-scale firms accounted for 17% of the study population indicated that they use it sometimes, 25% rarely use it, and only 4% use it very often.

The respondents justified this in their answers to the next question about the reasons, where the majority chose answered that it is not important for their business. This describes the high responses regarding the responsibility of implementation, where the majority see that it is the policy makers’ responsibility to apply regulations of the code. In this context, the authors agree with that point of view that policy makers have great responsibility regarding this matter following precedent experiences in other countries such as UK and UAE. In addition, the authors support the point of view of the big role of AEC firms in encouraging the stakeholders for a better consideration to the energy efficiency aspects in building sector.

In addition to this, the academic level of the design team was confirmed to be an essential factor for the attendance or absence of the ERBEC within the firms’ design process due to the knowledge gained in post graduate studies regarding building codes in general and the ERBIC in particular. Moreover, the economic aspects seem to be essential in the decision making on whether to be guided or not by the ERBEC in the design process, where the majority of the projects held by the firms are in the private high income category, then decreased towards
the lower economical level respectively, as a sequence, a strong positive relation between housing project economical level and applying ERBEC investigated, as income level increases, the code implementation increases.

Additionally, the competitive nature of the Egyptian design market forces all the stakeholders to produce big quantities of design production in limited time without having sufficient time to add the environmental aspects into consideration, consequently, the use of building energy codes is usually a hard decision to make in such a rush of time.

This demonstrates the urgent need of enhancing the awareness of the Egyptian architectural design community of the great importance of addressing the ERBEC starting from the early stages. The benefits to promote taking in consideration the energy efficiency aspects in building design sector and its advantages on the running costs of buildings should encourage the stakeholders to adopt it in their projects.

References


Annex 1. The Study questionnaire

<table>
<thead>
<tr>
<th>Q1. How many employees work in your firm?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1○ 1 - 9</td>
</tr>
<tr>
<td>1.2○ 10 - 49</td>
</tr>
<tr>
<td>1.3○ 50 or more</td>
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<table>
<thead>
<tr>
<th>Q2. What are the academic qualifications of the members within the design team of your firm?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1○ Bachelor’s degree</td>
</tr>
<tr>
<td>2.2○ Bachelor and Post graduate degree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q3. Which economic level of the residential projects does your firm work in? (select all applicable answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1☐ Low income housing</td>
</tr>
<tr>
<td>3.2☐ Middle income housing</td>
</tr>
<tr>
<td>3.3☐ Upper-middle income housing</td>
</tr>
<tr>
<td>3.4☐ High income residential</td>
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<table>
<thead>
<tr>
<th>Q4. For which sector your firm design most of the housing projects?</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1○ Private Sector</td>
</tr>
<tr>
<td>4.2○ Governmental Sector</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q5. Has your firm ever used the Egyptian Residential Building Energy Code in any of the firm’s residential projects?</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1○ Very often</td>
</tr>
<tr>
<td>5.2○ Sometimes</td>
</tr>
<tr>
<td>5.3○ Rarely</td>
</tr>
<tr>
<td>5.4○ Not applicable</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Q6. What are the obstacles that may prevent applying code requirements?</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1O I have never heard about it before.</td>
</tr>
<tr>
<td>6.2O I have never heard about it before, and I will reconsider it.</td>
</tr>
<tr>
<td>6.3O I know code's requirements, but I have not tried to apply it or provide the idea to clients.</td>
</tr>
<tr>
<td>6.4O I know code's requirements and I present the idea to the client, but they refuse it because of the high cost or other reasons.</td>
</tr>
<tr>
<td>6.5O I know code's requirements, but in fact it does not fall into the attention of the market.</td>
</tr>
<tr>
<td>6.6O I know code's requirements, but we use another energy efficiency codes and references in residential buildings.</td>
</tr>
<tr>
<td>6.7O I already apply code's requirements.</td>
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</tbody>
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<tr>
<th>Q7. From your practical experience, who is responsible for taking the decision of using or not the ERBEC?</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1O Architect</td>
</tr>
<tr>
<td>7.2O Client</td>
</tr>
<tr>
<td>7.3O authorized authority to issue licenses</td>
</tr>
</tbody>
</table>
Success or Failure? Energy Concept and Post Occupancy Evaluation of a new built Energy-Surplus Day-care Centre for Children

Michaela Hoppe

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Abstract: This new construction of an energy-surplus day-care centre in southern Germany illustrates how ecological and economic sustainability can go along with innovative techniques and architectural design, targeting to reach high comfort and energy efficiency, and simultaneously providing child-oriented and pleasant surroundings. The intention of this lighthouse project was to increase awareness and interest for the topic of energy efficiency within the municipality and beyond. The energy concept, focusing on minimizing the energy need, includes a variety of features, partially influencing each other. Amongst others, these include a high level of thermal insulation, an optimized and demand-controlled ventilation system with preheated air and heat recovery in winter, a solar chimney for passive cooling and ventilation in summer, intelligent control systems and the use of renewable energy sources. In a monitoring phase, recording the building’s thermal performance in the first two years of its occupancy, it was proven, that the central goal, the production of a surplus of energy for the operation of the building, was met, even though the technical systems were not operated correctly in the first months. This underlines the need of implementing integrated planning processes into the (German) standard building planning phases (HOAI, 2013). The results of a post occupancy survey illustrate the occupants’ difficulties to handle the complex energy systems, thus emphasizing the necessity to involve the future occupants from an early planning stage on.

Keywords: energy-surplus building, post occupancy evaluation, integrated planning process, user participation

Introduction

Induced by the dedication of the mayor and public participation within a municipality near south of Munich, Germany, the need of generating new child care facilities led to the realisation of an energy-surplus day-care centre. The building illustrates how ecological and economic sustainability can go along with innovative techniques and architectural design, reaching high comfort and energy efficiency, and simultaneously providing a child-oriented

Figure 1. West façade including the main entrance. The size of the windows and the entrance’s glazing indicate the maximized use of daylight.
and enjoyable surrounding. This lighthouse project aims on increasing awareness and interest within the community and beyond for the issue of energy efficiency.

In order to ensure the successful implementation of this demanding task, a qualified team of architects, installation engineers and researchers worked together from the very beginning of the design process, joining forces and knowledge. This includes scientific guidance in planning, construction and start-up along with a two-year monitoring.

The Building

Climatic Context

The climate in southern Germany is humid continental. The warmest month is July, with an average of min. 12 / max. 22° C, the coolest January, with an average of min. -4 / max. 2° C. The higher elevation and proximity to the Alps cause more rain and snow than in other parts of Germany. Warm downhill wind from the Alps (“Föhn”) however can raise temperatures sharply within a few hours, even in winter.

Architectural Concept

In order to achieve a versatile-use, multifunctional and appealing as well as high comfort energy-surplus building, it was essential to detect the energy potential already in the

Figure 2. Schematic illustrations of the building’s section (above) and ground floor plan (below), demonstrating the optimization of solar gains (internal as well as on the photovoltaic system) and the separate outdoor areas for the different groups of children.
Figure 3. The ground-floor plans (below: basement, middle: ground floor, top: top floor) show the layout of the rooms and illustrate the lowered south-side terrace in the style (no scale, north is to the left)
building’s early design phase. In this context, the elongated, north-south oriented building site posed a particular challenge for the design team. However, the central aspects of southern orientation and compactness could successfully be implemented in the developed building design, as depicted in Figures 2 and 3.

The compact building is located in the centre of the site, with an enlarged southern façade created by a lowered south-side terrace in the style of an amphitheatre. In this way, an additional independent external area is created, allowing for a trouble-free co-existence of children of different age. The terraced structure of the building creates further separated spaces and maximizes natural lighting as well as solar gains in winter.

To allow a maximum flexibility the different sections (which are currently suited for three different age groups) are organized in the same way. Thus, they can be converted accordingly, if necessary. All common rooms are accessible via the large two-storey entrance hall, by passing the cloakroom. Each section can be used by two groups and consists of two common rooms, with separate leisure rooms as well as one common room in between. The bathrooms are also to be shared between the two groups, their layout adapted to the children’s age (Figure 3)

**Energy Concept and Technical Components**

Besides the above stated significant aspects of the building design regarding energy performance, the energy concept includes a highly insulating building envelope as well as other innovative technical systems, which will be described in the following:

**a) Building Envelope**

- building components with extremely low heat transfer coefficients (U-values) e.g. due to installation of vacuum insulation and (by then) new types of triple glazing
- prevention of thermal bridges
- high level air-tightness

**b) Hybrid Ventilation System**

The hybrid ventilation system, which enables passive cooling and ventilation in summer, noticeably reduces the building’s energy demand for heating, cooling and ventilation. It comprises the following measures and systems and is schematically depicted in Figure 4,

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**Figure 4.** Schematic illustration of the building’s hybrid ventilation system, which is optimized by a vertical transverse flow system supported by a solar chimney above the central hall (no scale)
- using an innovative ventilation system with:
  . preheating of the supply air (via ground water)
  . highly innovative heat recovery system with a recovery rate of 90% due to use of heat accumulators (made possible and supported by air preheating)
  . demand-driven, reduced basic ventilation, supplemented by systematic manual window Ventilation
- ensuring day-time ventilation and passive cooling by night-time ventilation, to allow the shutdown of the HVAC-system during the summer months:
  . installation of sufficiently large, energy-optimized ventilation flaps in the exterior façade and towards the foyer
  . installation of a solar chimney (Figure 5) on the roof of the foyer to support summer ventilation and passive cooling by night-time ventilation

c) Intelligent Control Systems and Lighting
The use of intelligent control systems enables a further reduction of the energy demand for heating, cooling, ventilation and lighting:

- automatic shutdown of space heating when windows are opened
- use of CO₂-sensors and “ventilation lights” (indicating the CO₂-level, e.g. by coloured lights like a traffic light) for energy-optimized and demand-controlled ventilation and to raise the children’s awareness thereof

Figure 5. Elevation and section of the solar chimney, exclusively developed for this day care centre to support summer-time ventilation with vertical transverse flow and passive cooling by night-time ventilation
- automatic control of the solar chimney:
  . automatic and intelligent activation of night-time ventilation for passive cooling in case of high interior temperatures
  . navigation of the lateral openings depending on the wind direction
  . energy-optimized control of action period and mode of operation of the heat generators (2 ground water heat pumps and solar hot water generation)
- reduction of the electricity need for artificial lighting by maximizing daylight supply and using intelligent control systems:
  . daylight redirecting shading systems
  . daylight-dependent control systems (in common rooms and offices)
  . presence detection systems (in bathrooms and hallways)

\textit{d) Low Exergy Heating System}
The following components ensure the effective coverage of the remaining minimized energy requirement:

- very low temperature level for energy optimization and the effective use of heat pumps
- hot water generation by solar collectors, optimally oriented and aligned
- decentralized freshwater stations to eliminate hygienic problems caused by the low temperature level
- combination of two highly efficient groundwater heat pumps with enhanced annual coefficients of performance and well-matched components

\textit{e) Solar Power System (Photovoltaic PV)}
For the operation of the above presented building with its energy concept, the only energy carrier required is electricity, apart from the natural renewable sources of solar and geothermal energy. To generate this electricity photovoltaic modules are set up on the entire roof area above the second floor as well as on a steel frame installed on the first-floor roof terrace. The sizing of the PV system is adjusted, so that more electricity is generated throughout one year than needed, leading to the building’s energy surplus.

\textit{The Building’s Energy Performance}
During the design phase various options and variants regarding design, construction and energy concept were discussed. For rating and comparing these different energy performances and for evaluating the final draft of the children’s day care centre as energy-surplus building, calculations were performed according to the German standard “DIN V 18599: Energy efficiency of buildings - Calculation of the energy needs, delivered energy and primary energy for heating, cooling, ventilation, domestic hot water and lighting” (DIN V 18599, 2007)

To obtain realistic energy demand values - instead of standardized parameters as required for energy performance certificates according to the German Energy Saving Ordinance (EnEV, 2009) - user and site-specific boundary conditions were used as well as characteristic values planned, wherever possible. The following table shows the resulting area-specific energy values for energy need, delivered and primary energy, where the solar-
generated electricity is not included. Taking into account the electricity generated by the PV system, the delivered and primary energy are less than zero due to the surplus derived.

Table 1. Results of the building’s energy performance rating according to the German standard DIN V 18599 (without considering the photovoltaic system) (IBP, 2006-2015)

<table>
<thead>
<tr>
<th>Energy Demand (PV system not included)</th>
<th>Energy need [MWh/a]</th>
<th>Delivered Energy* [MWh/a]</th>
<th>Primary Energy** [MWh/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>17.7</td>
<td>4.8</td>
<td>12.5</td>
</tr>
<tr>
<td>DHW</td>
<td>13.5</td>
<td>4.7</td>
<td>12.1</td>
</tr>
<tr>
<td>Lighting</td>
<td>8.0</td>
<td>8.0</td>
<td>20.8</td>
</tr>
<tr>
<td>Ventilation</td>
<td>0</td>
<td>7.3</td>
<td>19.9</td>
</tr>
<tr>
<td>Total</td>
<td>39.2</td>
<td>24.7</td>
<td>64.3</td>
</tr>
<tr>
<td>Reference Value***</td>
<td>55.4</td>
<td>75.1</td>
<td>105.2</td>
</tr>
</tbody>
</table>

* Electricity is the only energy carrier used. Considering the need throughout the year, it is solely produced by the rooftop photovoltaic system, even more than required, thus generating a surplus.

** Primary factor applied is 2.6.

*** Not conforming to the regulation, just to be considered as benchmark, helping interpreting the results.

Although the energy values of the table above are not to be applied for an “EnEV-Certificate”, the table’s last line shows comparative values of an approximate reference building according to EnEV 2009 (EnEV, 2009), to show the order of the values’ magnitude. This shows that the designed building requires less than half the primary energy allowed according to EnEV 2009 (EnEV, 2009), even without taking the PV system into account.

The photovoltaic installation will be sized to produce more electricity than required within one year. This includes the operation of the building as well as additional power required for all devices used in the building, such as kitchen appliances, computers, stereos, etc. The energy need thereof is estimated with 10-11 MWh per year. In total a surplus of about five thousand kilowatt hours per year is aimed at, equivalent to almost 15% of the overall electricity need of approximately 35 MWh/a.

Post Occupancy Evaluation

For a successful operation of a high-tech building like this, its initial start-up plays a crucial role as a variety of systems must be calibrated and many systems depend on each other. In addition, the results are of great interest for everyone involved, especially in order to draw conclusions for future energy-efficient buildings. The planning and execution of the monitoring system were incorporated by a scientific advisory board from Fraunhofer Institute of Building Physics (IBP), supervising the project from the very beginning regarding energy issues (including planning, construction supervision, measurement and monitoring). The monitoring, executed by Rosenheim University of Applied Sciences, ran for two more years after the building was successfully put into operation in autumn 2013.

Energy Performance

Table 2 illustrates the monthly balance of accumulated energy as identified by the monitoring team from Rosenheim University of Applied Sciences (Wambsganß, et al., 2016). The chart
shows clearly that from mid-summer 2014 on the building produced more electricity than it needed. The surplus was fed it into the grid.

The following year the PV panels got damaged by strong wind, nevertheless – due to its orientation, compactness, thermal envelope etc. - the building still produced more energy than necessary. The monitoring results verify the high energy efficiency of the building and thus underline the successful planning.

**User Acceptance**

In terms of user acceptance things look slightly different: a survey undertaken by the Karlsruhe Institute of Technology (Schakib-Ekbatan & Roser, 2015) shows that the child carers working in the building are not satisfied with the interior climate provided by the building and its technical components. Table 3 shows the answers of 9 out of 15 interviewees responding to a questionnaire examining their overall satisfaction with the building. The team rated different questions affecting different comfort aspects according to the German school rating system (1 = very good/outstanding – 5 = not sufficient). Especially the negative results concerning thermal comfort in summer and indoor air quality seem to be surprising, considering the high level technical system installed, supposed to provide optimal conditions.

**Table 2.** Monthly balance of accumulated energy as identified by the monitoring team from Rosenheim University of Applied Sciences (Wambsganß, et al., 2016)
Table 3. Answers of 9 out of 15 interviewees responding to a questionnaire examining their overall satisfaction with the building (Schakib-Ekbatan & Roser, 2015) according to the German school rating system (1 = excellent – 5 = not sufficient).

What do I think/feel about...

Possible explanations

In order to find out the reasons for this low user acceptance a further interview between the author, the team and the caretaker took place in autumn 2017.

Inappropriate operation of technical systems

The main aspect stated in that conversation was that the technical appliances were not taken into operation properly. The HVAC-system, supposed to provide well-tempered and fresh air while recovering heat from the outgoing air causes a slight, but apparently nerving, whistling noise. Therefore, the team turns the HVAC-system off whenever possible. Recent maintenance works have shown that the air filters had been installed incorrectly, causing the acoustic inconvenience.

Technology Antipathy

Another critical feature pointed out by the team are the motor driven window openers. Operated by a little switch attached to an internal wall the child carers can’t tell whether the window is closed properly or not. Due to the above mentioned automatic shutdown this sometimes causes the heating system to be shut down not deliberately. To make things worse the opening or closing process of the windows is rather time-consuming, and the motors brake frequently causing high reparation costs. As Table 4 shows the team would definitely prefer a manual operation of the windows.
Due to the building’s technical complexity there was a caretaker employed, who is responsible for the technical systems. In consequence the teaching team is not in control of the technical systems and, as a result, not operating features crucial for a positive performance e.g. the solar chimney. Thus, the users do not identify the advantages of the natural ventilation system as intended.

Table 4. Answers of 9 out of 15 interviewees responding to a questionnaire examining their preferences for operating the windows (Schakib-Ekbatan & Roser, 2015)

![Graph showing preferences for operating windows](image)

**Automation overload**
In addition, the caretaker got no special training in e.g. building automation. So on occasional situations he has to contact supporting software engineers. As a result of the original firm’s inexperience\(^1\) the building automation steering the night ventilation did not work properly for the first years, so the PCM-modules were not unloaded successfully at night. (Things work far better with the present firm, though.)

**Missing integration into the pedagogical concept**
The visualization of the buildings energy performance, as on display in entrance area, is shown in Figure 6. Interested parents or other visitors do have the chance to inform themselves about the building. Beyond that, the energy system and its technical components do not play a decisive role in the pedagogical concept.

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\(^1\) Due to public procurement policies it is not necessarily the best qualified provider that has to be assigned.
Lessons learnt

Four years after putting the building into service it gets evident that the building performs successfully in terms of energy efficiency: even in the second year of its usage – despite the partial solar panel drop out caused by a storm – the annual energy gains meet the annual energy needs. Relating to the planning process and the start-up phase, however, there is some room for improvement:

1. A better integration of the future user into the planning process would make it easier for both, planners and users, to implement technical measures that are matching the intended usage more precisely.
2. The technology implemented should be self-explaining and allow an intuitive usability. The user should always have the opportunity to overdrive the technical system in order to enhance user acceptance.
3. A precise description of the building functions, the harmonisation of usage and energy concept and a carefully organized introduction to the technical systems contribute to a better understanding of the buildings operation. Non-functioning technical components do lead to an antipathy against energy efficiency.
4. The existing planning phases according to the German “Official Scale of Fees for Services by architects and Engineers” (HOAI, 2013) should be extended by an obligatory optimization phase which would extend the planners’ responsibilities and thus allow a smoother start-up process.

The project presented here shows that it is technically possible to construct buildings that produce more energy than annually needed. The future challenge is to find, or maybe rediscover, self-explaining low tech solutions that provide an equivalent level of energy efficiency in combination with a high thermal comfort, that are at the same time easy and stress-free to operate and therefore lead to an excellent user acceptance in addition.
Acknowledgements

Special thanks shall be given to

- the municipal council of Höhenkirchen-Siegertsbrunn, Germany, especially the mayor, Mrs. Ursula Mayer;
- the Federal Ministry of Economics and Technology (BMWi) for their financial support within the Research for Energy-optimized Construction Programme (EnOB, 2010);
- the planning partners from Fraunhofer Institute of Building Physics (IBP), Stuttgart, Germany, Asböck Architekten, Munich, Germany, Bloos Däumling Huber, Munich, Germany, IB Wilhelm, Stubenberg, Germany and Merz Key Partner ZT, Dornbirn, Austria;
- the monitoring teams from Rosenheim University of Applies Sciences, Rosenheim, Germany and the Institute for Resource Efficiency and Energy Strategies (IREES), Karlsruhe, Germany and
- the whole team of Arche Noah Day-Care Centre, Höhenkirchen-Siegertsbrunn, Germany.

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IMPLEMENTING SELECTED PASSIVE COOLING DESIGNS ON THE HOUSING TYPOLOGIES: CASE STUDY OF FUJAIRAH IN UAE

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Abstract: Passive design replies to context of the local climate and location characteristics to maximize the comfort and health of end users with reducing energy use as well. The aim of this paper is to investigate the effect of applying selected passive cooling designs on the Housing Typologies in Fujairah Emirates. A double story villas in Fujairah Emirate in UAE was selected to act as a main case study. With the aid of IES simulation software, the building performance was evaluated before and after applying passive cooling strategies which include green roofs, shading device and evaporative cooling by roof pond. The new strategies achieved improvements, for example, the new shading device contributes to a better visual comfort and daylight factor was improved form 2% to 5%. Moreover, the new green wall reduced the U-Value from 2.97 W/m2K to 0.12 W/m2K. it is worth mentioning that these interesting findings may be applicable to the countries that share similar environmental and social context of UAE.

Keywords: Passive Design, arid, passive design strategies, UAE, IES

Introduction

Climate change still a hot issue those days with all what happens worldwide in continuous rising of temperature and many natural disasters which affects lives and produce high cost implications in the entire planet (Ban Ki-moon, 2014). The drive of this paper is to explore the passive cooling techniques outcomes of selected passive factors on the outdoor climate air temperature, wind velocity, shading, daylight and glare of housing units, and then analyse it using the IES Virtual Environment (IESVE) program compare the designs and strategies within timeline frame to achieve and improve thermal performance in order to obtain the optimum energy reduction by indicating and investigating various characteristics such as orientation, used materials, natural ventilation and so on.. Passive design speaks to the context of the local climate and location characteristics to maximize the comfort and health of end users while also reducing energy use. The key to successfully granting an effective passive project is to take the greatest advantage of the local climate context. Passive cooling techniques are defined as technologies or designs that aim to decrease the temperature of a project without using power consumption. Consequently, the aim of this study is to examine the effectiveness of using the selected passive cooling strategies and to decrease energy consumption of residential houses in hot arid climate settings.

The UAE, focusing on Fujairah Emirate, has noticed a fast trend boosted in the construction sector that is influenced by three levels: economic, infrastructure and urbanization level. This leads to sustainable development throughout the construction market within the UAE, particularly in the traditional and national houses, which faced challenges such as unpredicted change, and basically transformation and renovation all houses’ typologies in terms of architectural designs and used technologies.
The highest energy consumer in the UAE in 2015 was the commercial sector, followed by the residential sector consumes at 30%, which generates essential problems in balancing the power supply and the demand, (Ministry of Energy 2015). As shown in Figure 1, in Federal Electricity and Water Authority (FEWA) which provides Fujairah Emirates with power along with other northern emirates, the residential sector is largest electricity consumer among the other sectors with 41%, (Ministry of Energy, 2015).

![Electricity consumed by sectors (GWH), in 2015](image)

Figure 1: FEWA consumption in Northern Emirates, (Ministry of Energy, 2015).

**Climatic data**

For this paper, a case study was selected in Fujairah Emirate to assess building performance with a house unit design. Fujairah is one of the seven emirates in the UAE, and its focus is to develop gradually; it has a very strategic location and Fujairah port is ranked the second in global bunkering. The house unit will be analyzed throughout the six months of summer climate and weather conditions in Fujairah Emirates. As these particular inputs influence the design, all the used building materials shall be specified such as insulation and orientation of the buildings in order to get accurate results to minimize the energy consumption. The period of daylight in a day is predicted to be from 06:46 AM to 18:11 PM, which is almost 11 hours, 25 minutes, and it differs from summer to winter, where the study will take place in April 2016. Figure 2, present the annual temperature in Fujairah Emirates ranges from highest 49 C in June with a climate that is harsh, hot and above the comfort zone in nine months and only in December to March in 2014m where it reach the comfort zone.

![Figure 2: Temperature in Fujairah Emirates 2014, Source: (WorldWeatherOnline.com, 2014)](image)

Similarly Figure 3, prove that the electricity consumption increase from April to November and start to decrease from December to March, 2014.

![Figure 3: Fujairah Emirates power consumption in 2014, Source: (Federal Electricity & Water Authority, 2015)](image)
Literature review

This literature review discusses work on sustainable development strategies and techniques of thermal performance and energy consumption optimization among traditional houses and vernacular architecture when the climate was the main influence on people’s attitudes and behaviours, house forms and their architectural design in order to achieve satisfactory levels of comfort, and through construction development evolution within the timeline frame. The obtainable studies’ emphasis is mainly on some of the passive techniques that lower power consumption with optimization of thermal comfort.

Passive design strategies and the location of a building have a significant relationship. The orientation of the building should be considered in the design phase and they have to calculate the amount of daylight that enters in the building as well as the ventilation. The roof considered to be the main source of solar radiation as it faces the sun in direct way especially in the harsh, hot and dry climates (Meyer, 1982).

Increasing the daylight and decreasing the glare is the way to achieve better visual comfort and increase productivity of the occupant (Fiocchi et al., 2011). Anderson and Michal (1978) state that passive design is installed in the buildings to improve the thermal performance in the interior environment, while reducing energy consumption; as one of the advantage of the passive design is to utilize and consider the wind direction and the sun path as it excludes electrical and mechanical support taking into consideration the location requirements such as orientation, the availability of the local materials, shape of the building and other parameters. A lot of passive design strategies can be considered such as those related to the building orientation, green roof or walls, insulation, shading techniques, internal courtyards, wind tower, evaporative cooling, earth air tunnels, passive down draught cooling, roof, natural ventilation, etc.

Three strategies were selected, which are as follows: green wall (GW) (modular living wall), evaporated cooling (roof pond) and shading devices (vertical fins). The main reason for selecting these strategies is that in a typical UAE house 30% of all heat gains happen through its roof and 30% through walls. And providing a high thermal insulation on the building envelope is considered an effective passive cooling technique as it prevents heat from getting into the building. In the UAE house, 30% of solar gains result from the roof and about 30% from walls. To decrease solar gain, increasing the insulating construction materials can be deployed and applied in the building envelope (Khodakarami, 2009).

Green roof organization (2008) defines GW or vertical gardens as all forms of plantation wall surfaces. There are many benefits to GW such as beautification and purification for the environment. Also, they can capture heated gas in the air, reduce the temperature for the interior and exterior, and offer healthier indoor air quality in addition to the beautiful space (Yeh, 2012). Stav (2008) states that in the 1980s, the environmental issues in Europe were tackled and received great interest, so they were incentivized to encourage green façade adaptation. Thompson and Sorvig (2000) stated that GW grasps or slows rain water, offers food and shelter for particular wildlife. Green all can be Implemented outside and they are categorized into two types: façade system and living wall system (Sable &Sharp, n. p.) or inside within the building envelope context in different country and different climate. Different shapes, structure, design, insulation and maintenance can be easily implemented to deploy the Green wall with different type of plantation use.
For this paper, living walls (modular living walls) will be selected, since it has a great influence on the u-value and lowers the heat gain. The type of plantation selection will be decided upon the local context of Fujairah Emirate. The selected system used is a GW, modular living wall, and it’s used externally in hot climate countries. It contains several parameters such as the planter, soil, plants and, optionally, a drip watering system. Modular living walls contain polypropylene modules (Sable, J. & Sharp, R, 2008). Shading is considered another significant design strategy that affects thermal comfort levels in the UAE due to the greater solar gains that are received by buildings. Shading devices are accomplished through different strategies like self-shading, overhangs on windows, building clustering, planting high trees, and designing shading features.

The shading devices have a direct influence on a building’s performance, either in terms of daylight and ventilation or solar gain. Bellia et al. (2013) study the effect of shading devices on the energy demands of a typical office building in Italy. They compare the impacts on three cities, which have different climates. The results show that incorporating shading devices on buildings in hotter climates is more effective than in colder climates, where the savings in Milan (cold climate) were simulated to be 8% as opposed to 20% in Palmero (Bellia et al., 2013). The results show that optimum configurations of the solar screens caused up to 30% savings in the south and west, 25% in the east and 7% in the north (Sherif et al., 2012). Although shading devices offers numerous advantages such as reducing the cooling loads as well as minimize the glare and monitor light intensity and monitor ration, few designers used the shading devices in their projects (Kensek et al., 1996).

Tzempelikos & Athienitis (2006), stated in their study that shading devices have significant implications for the power consumption in a building; a saving of 50% of total power consumption can be achieved by cooling as well as saving in solar and heat gain of with at least 12%. In another study the position of fins and the result for the west and east facades vertical fins has the best efficiency results; however for south facades horizontal fins achieved significant efficiency levels (Palmero-Marrero, 2009). Cetiner & Ozkan, (2004) argued that, the shading devices can dramatically reduce the energy demands and has significant cost efficient comparing the initial cost.

The evaporative cooling technique is used to lower the indoor air temperature by evaporating water. It is mostly effective in harsh, hot and dry climates with low atmospheric humidity. For this strategy, by evaporate water with the observable heat of air; on the other hand, cooling the air cools the occupied space within the building. Evaporative cooling was used in the past in various countries in the Middle East. A desert cooler was the common system used, which contains a fan, water, pump and evaporative pads.

In this paper, the roof-pond will be selected as the third strategy, whereby a roof pond can be described as a passive solar strategy when it acts as a heating and cooling technique with the assets of the natural environmental (Marlatt, Murray & Squire, 1984). The traditional roof pond contains horizontally oriented water mass positioned on the roof of a project (a flat roof is required). The roof pond can contain movable insulation panels that overtop the water bags at certain times for both the heating and cooling styles of procedure (Mazria, 1979). For this study the effect of the pond concrete structure will be examined on reducing the solar and heat gain on the roof only since the (IESVE), can’t analysis the evaporative cooling effect which considered indirect effect.

Lessons learned from Vernacular architecture, especially in the UAE, which has been greatly influenced by culture, the harsh environment, traditional lifestyles, limited resources, limited technology and tribal customs. The building materials that were used in the
construction were local ones that were simple, but also highly adapted to the requirements and demands of public lifestyles and harsh weather. For tribal culture, privacy and ventilation were essential and these impacted upon the planning of traditional houses and courtyards, which were designed in the centre of the house.

Beside the houses’ layout, design and local materials that helped to enhance the cool interiors, other additional features such as wind towers, called barjeel, were also used to increase natural ventilation. In the harsh, hot desert climate the wind tower tends to catch the wind stream and act like an air conditioning systems. No standardized design, dimension or shape was used to build those wind tower; they are remarkably large structures built on the roof to maximize the wind catchment.

Paper objectives

The paper contains both theoretic and technical overviews of sustainable housing development in the UAE concentrating on housing typologies within the following timeline frame and the following are the paper objectives:

- Create a timeline of housing typologies development and understand the sustainable evolution overtime in the UAE, especially in Fujairah Emirate.
- Site visit to provide a holistic idea about the housing typologies in Fujairah Emirates and determine their features.
- Adopt three main strategies of passive design solutions that have a large impact on power reduction and high levels of comfort.
- Select a case study (house) in Fujairah Emirate and investigate the effect of applying those strategies on the building by improving the thermal performance and analyzing the energy consumption in different timeline frames (past, present and future).

Methodology

A qualitative methodology will be adopted for this paper and a descriptive comparison will be conducted after extracting the analysis from the computer simulation for the case study within the timeline frame. The case study will be a house unit in Fujairah Emirate. The expected results are optimizing the power consumption through applying different strategies which will be compared to the base scenario and two standards the Estidama in Abu Dhabi and BREEAM in UK. In order to achieve the optimization in comfort levels taking in consideration reducing the power consumption a passive design can be adopted to gain a comprehensive integration for the microclimatic demands.

For this paper a brief exploration of the advanced building performance modelling and simulation will be conducted and graphical and diagrammatic results from IESVE presented. The IESVE program is used to assess the building performance to be able to obtain the optimum energy consumption by indicating and exploring various characteristics such as orientation, used materials and ventilation schemes; through this project the three strategies will be analyzed according to the mentioned analysis tools.

Conceptual framework

The following char represent this paper graphical methodology abstract:
Case study Description

The site is located in Al Bithnah area within a residential area. The selected house is oriented towards the North and the case study characteristics for the selected local/national house, in Ministry of Infrastructure and development (MOID), house model (765), which is double story with built up area of 408.34 square meters and 11 occupants. In addition to that, there are 15 air conditioners used and 11 water heater and the house age is 6 years. In addition to that, the actual electricity and water consumption for the selected case study the local house with the paid bills for 2015 were collected. The annual electricity consumption was 94739 (KWh) and the cost was 7105.425 AED, where the water consumption was 359900 gallon and the cost was 7198 AED.

Site Visit

A site visit was made to the base case model in the Al Bithnah area in Fujairah Emirates; the selected house was located in a mountain area. It was extremely beneficial to understand the real effect of the climate and weather conditions on the site as well as to see the opportunities for improving the thermal environment. From the site visit we noticed- that it is important to design the projects based upon the existing climate and weather conditions of each area individually, as well as taking into consideration the cultural aspects.

Building Envelope Performance

The thermal insulation characteristics and overall annual cooling load of the configurations used in the energy simulations tests are shown in table 1:

Table 1: The Thermal insulation characteristics and configurations

<table>
<thead>
<tr>
<th>Items</th>
<th>As build</th>
<th>ESTIDAMA one Pearl</th>
<th>BREEM New notional dwelling Part L1A 2013</th>
<th>From Literature review of passive house</th>
<th>Selected u-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall U-value (W/m² K)</td>
<td>2.97</td>
<td>0.32</td>
<td>0.18</td>
<td>Green wall: &lt; 0.15</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Assigned Scenarios

In this paper the following scenarios will be selected:

1. Green wall (GW) (modular living wall): the simulation will include the base model and then implementation of the GW on all the external wall of the villa will be examined.

2. Evaporated cooling (roof pond): the simulation will include the base model without the GW, then effect of the support structure of the roof pond only will be examined.

3. Shading devices (vertical fins): the simulation will include the base model, then vertical fins will distance of 30:30, after that vertical fins with distance of 50:50 be implemented.

4. Estidama standard (the peals rating system) scenario and BREEAM standard scenario compared will be implemented for all the selected strategies will be compared to the base case scenario.

5. Finally a combination of all the selected strategies will be implemented to find the optimum scenario.

Results

The case study is an existing villa and it was designed and built by MOID. It was selected to be analyzed to validate the examination and assessment using the IESVE analysis tools. Although the weather data was extracted from Fujairah International Airport, and derived from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zone, from the IES software options, Abu Dhabi climate data was used.
As noticed from Figure 6 a balance should be maintained between the solar gain and the daylight when using the shading device, in order to be able to gain a sufficient daylight with less solar gain. The radiance tool was studied to analyze the glare in the building environment as the ‘glare index’ shall not exceed 19 as per CIBSE (Chartered Institute of Building Services Engineers) glare index which is a pattern for the evaluation of discomfort. For this research the result shows that are no glare in all the proposed strategies or even the base case scenario. Building with artificial lighting can be incorporated with the daylighting by supplying electrical sources of light to reduce the glare.

For the first strategy (Green wall – modular living wall) and as shown in Figure 8, there are a huge difference in the conduction gain: external wall results for both Estidama standard scenario and BREEAM standard scenario compared to the base case scenario.

While in the second strategy (evaporated cooling – roof pond) and as shown in Figure 9, there is a huge difference in the conduction gain: roof results between both Estidama standard scenario and BREEAM standard scenario compared to the base case scenario.

As shown in Figure 10, for the third strategy (shading device – vertical fins) there are a huge difference in the conduction gain: roof results between both vertical fins with spacing of (30:30 cm) scenario and vertical fins with spacing of (50:50 cm) scenario compared to the base case scenario.
CFD-simulations tend to underestimate thermal discomfort if the CFD-results are applied without turbulence correction. The effect of the correction on air speed and draught rating values was found to be significant in room airflows with high turbulence intensity. It is especially large when considering average values in the occupied zone of room. The correction for the maximum speed or maximum draught rating in the room was, instead, smaller. It is recommended that the turbulence correction should be applied to CFD-results when calculating estimates for air speed, thermal comfort and draught risk. The method can easily be implemented in modern post-processors.

These low thermal comfort predictions may appear counterintuitive, as the air temperature is within the required design range of 20-24°C. However, according to the ASHRAE thermal sensation scale (2009 ASHRAE Handbook - Fundamentals, p9.11), a prediction where -2.0 < PMV < -1.0 indicates that occupants feel ‘cool’ to ‘slightly cool’. Since the ideal PMV is a value of zero (occupant thermal sensation is ‘neutral’, neither ‘warm’ nor ‘cool’), this result shows that the best results conducted through all the scenarios are the efficient scenario 1 and the final overall emerged strategies. Still, in terms of a summer design scenario, the simulations indicate that the cooling system has adequate capacity to sufficiently cool the analyzed spaces in this study air condition was included in the building design.
Discussions

As shown in Table 2, and as a common sense, there is no relationship between changing the specification of the external wall and the solar heat gain by lowering the u-value from base case from 2.97 to first scenario Estidama standard 0.32 and then the GW u-value of 0.12 (BREEAM standard), a huge difference in savings and reduction in both room cooling sensible point loads with 48% (Estidama standard) and 52% (BREEAM standard) reduction, and the annual electricity with 38% (Estidama standard) and 41% (BREEAM standard) reduction.

<table>
<thead>
<tr>
<th>Items/ strategy</th>
<th>Base case</th>
<th>1st scenario (Estidama)</th>
<th>Efficient scenario (Green wall)</th>
<th>Savings/ reduction, from 1st scenario</th>
<th>Savings/ reduction, from Efficient scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Heat Gain (MWh)</td>
<td>0.572</td>
<td>0.572</td>
<td>0.572</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Room cooling Sensible point MWh</td>
<td>179.84</td>
<td>93.2</td>
<td>86.2</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>Annual Electricity (MWh)</td>
<td>128.93</td>
<td>79.62</td>
<td>75.92</td>
<td>38%</td>
<td>41%</td>
</tr>
</tbody>
</table>

In Table 3, similar results were found as there is no relationship between changing the specification of the roof and the solar heat gain, by lowering the u-value from base case 2.90 to first scenario Estidama standard 0.14 and to the roof pond u-value of 0.10 (BREEAM standard). While there is a significant difference in savings and reduction in both room cooling sensible point loads with a 20% reduction for both Estidama standard and BREEAM standard, and the annual electricity with a 13% reduction for both Estidama standard and BREEAM standard. And, as shown, there is no significant difference in changing the roof u-value from 0.14 to 0.10 where the difference is negligible.

<table>
<thead>
<tr>
<th>Items/ Roof Pond strategy</th>
<th>Base case</th>
<th>1st scenario (Estidama)</th>
<th>Efficient scenario (BREEAM)</th>
<th>Savings/ reduction, from 1st scenario</th>
<th>Savings/ reduction, from Efficient scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Heat Gain (MWh)</td>
<td>1.775</td>
<td>1.775</td>
<td>1.775</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Room cooling Sensible point MWh</td>
<td>179.84</td>
<td>144.50</td>
<td>143.92</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Annual Electricity (MWh)</td>
<td>128.93</td>
<td>112.55</td>
<td>112.28</td>
<td>13%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Opposite results were found by applying vertical fins to all the windows for the case study; as shown in Table 4, this applied strategy has a strong relationship and the solar heat gain by using different width and distance in the two scenarios. For the first scenario is vertical fins of 30:30 cm in distance was applied and the reduction and savings was 58% in solar heat gain, while in the efficient scenario a vertical fin of 50: 50 cm in distance was applied and the reduction and savings was 56% in solar heat gain. A considerable difference in savings and reduction in both room cooling sensible point loads with 4% reduction for 30:30 cm design and 10% for 50:50 cm design, and the annual electricity with 3% reduction for 30:30 cm design and 9% for 50:50 cm design.
Table 4: IES – VE analysis results for the third strategy Shading device - Vertical Fins

<table>
<thead>
<tr>
<th>Items/ Vertical Fins strategy</th>
<th>Base case</th>
<th>1st scenario</th>
<th>Efficient scenario</th>
<th>Savings/reduction, from 1st scenario</th>
<th>Savings/reduction, from Efficient scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Heat Gain (MWh)</td>
<td>1.055</td>
<td>0.44</td>
<td>0.46</td>
<td>58%</td>
<td>56%</td>
</tr>
<tr>
<td>Room cooling Sensible point MWh</td>
<td>179.84</td>
<td>172.79</td>
<td>162.03</td>
<td>4%</td>
<td>10%</td>
</tr>
<tr>
<td>Annual Electricity (MWh)</td>
<td>128.93</td>
<td>125.53</td>
<td>117.70</td>
<td>3%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Comparing both overall merged strategies, where efficient scenario one is a combination of external wall u-value 0.32 (W/m2 K), roof u-value 0.14 (W/m2 K) and vertical fins (30:30 cm). On the other hand, efficient scenario two is a combination of external wall u-value 0.12 (W/m2 K), roof u-value 0.10 (W/m2 K) and vertical fins (50:50 cm). The results were high in the efficient scenario two with room cooling sensible point loads of 82% for BREEAM standard reduction, and the annual electricity of 64% for BREEAM standard reduction, as shown in Table 5.

Table 5: IES – VE analysis results for the overall merged strategies

<table>
<thead>
<tr>
<th>Items/Optimum strategy</th>
<th>Base case</th>
<th>Efficient scenario 1</th>
<th>Efficient scenario 2</th>
<th>Savings/reduction, from 1st scenario</th>
<th>Savings/reduction, from Efficient scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room cooling Sensible point MWh</td>
<td>179.84</td>
<td>42.26</td>
<td>32.62</td>
<td>76%</td>
<td>82%</td>
</tr>
<tr>
<td>Annual Electricity (MWh)</td>
<td>128.93</td>
<td>53.96</td>
<td>46.87</td>
<td>58%</td>
<td>64%</td>
</tr>
</tbody>
</table>

The results of the final overall merged strategies (which are a combination of external wall u-value 0.14 (W/m2 K), roof u-value 0.10 (W/m2 K), vertical fins (50:50 cm) and glazing u-value 2.2 (W/m2 K), have the highest among all alternatives, since the u-value of the glazing for the external windows changed as it was 5.57 (W/m2 K) in all scenarios to a lower u-value of 2.2 (W/m2 K), which is a common value used in Estidama and BREEAM standards. Although the reduction was the highest among all scenarios, the costs of applying such strategies all together is very high compared to the other scenarios, as shown in Table 6.

Table 6: IES – VE analysis results for the efficient overall merged strategy with glazing u value of 2.2

<table>
<thead>
<tr>
<th>Items/Optimum strategy</th>
<th>Base case</th>
<th>Final overall merged strategies</th>
<th>Savings/reduction, from 1st scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room cooling Sensible point MWh</td>
<td>179.84</td>
<td>18.78</td>
<td>90%</td>
</tr>
<tr>
<td>Annual Electricity (MWh)</td>
<td>128.93</td>
<td>39.88</td>
<td>69%</td>
</tr>
</tbody>
</table>

The results show the potential to reduce building energy consumption, and the building with different strategies that can reduce total energy consumption the most, and has better thermal performance than the others, is efficient scenario two under most conditions. In general, the building with proper design (the efficient scenarios) requires less energy for cooling and heating compared with the building in the base case model.

Conclusions

The relationship between the design, geographical location, daylight and orientation was proven. The passive design strategies which were tested in this study have significant implications for total electricity costs, solar gain and cooling loads. The selected strategies...
are used to reduce power consumption, cooling the indoor air without raising its moisture and reducing the heat gain in the daytime. A roof pond is placed on top of the roof and it contains a water pool made of plastic or fiberglass. Different types of covers can be used to cover the pond either by removable cover, a fixed cover or even a fixed floating installation. The result of this technique was considered for the pond structure only. The results show the potential to reduce building energy consumption, and the building that has different strategies that can reduce total energy consumption the most, and has better thermal performance than the others, is efficient scenario two under most conditions. In general, the building with proper design (the efficient scenarios) requires less energy for cooling and heating compared with the building with base case.

In future papers, a study of the life cycle costs can be studied to evaluate the strategies and the different merged options from a financial point of view. Ministry of infrastructure development (MOID) is aiming to lower the emission in their design of residential houses to maintain sustainability by consider using some of those strategies as well as using green building codes, local materials to achieve UAE 2021 vision and the UAE National Agenda KPI’s which are both aligned with the sustainable development goals 2030 set by United Nation.

References

ADOPTING GREEN BUILDING MATERIALS AND MODERN TECHNOLOGY IN VERNACULAR APPROACH LEADS SUSTAINABLE FUTURE

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Abstract: At present, the effects of climate change is becoming increasingly apparent and as the economy rises and the population is moving up in developing country. Globally, it has been estimated that a building consumes approximately 40% of the total world’s energy and responsible for 50% of greenhouse gas emissions. It has been projected that building-related greenhouse gas emissions reached 8.6 billion metric tons CO2 equivalent in 2004, and expected to grow to 26% by 2030, reaching 15.6 billion CO2 under their high-growth scenario. This research paper presents the advantages of sustainability methods followed in vernacular style of architecture buildings. To resolve the energy consumption crises, it will be necessary to introduce the concept of ‘sustainable development’. Firstly the research consist of case study which was conducted on a village Jadi, chakrata Tehsil in dehradun district of uttarakhand state, India. Two types of houses namely Pakka houses, conventional building (constructed using conventional building materials) and katcha houses, vernacular house (constructed using green non-conventional building materials) to review with the sustainability concept and proves pakka houses doesn’t pay lesser foot print on environment and consume more energy. Secondly to provide a better solution for sustainable future, incorporating latest green technology in to vernacular styled shelters is highly recommended.

Keywords: sustainability development, vernacular architecture, green technology, carbon emission, building energy consumption

Introduction

Today, the effects of climate changes which first becoming increasingly apparent as the economy rises and the population is moving up, a great amount of new construction is required. Contemporary architecture practice and construction depends excessively on high energy materials, which consumes a lot of energy. It is well recognised that world energy consumption is divided into three major economic sectors: i) buildings (27% Energy); ii) transportation (27% Energy) and; iii) industrial (25% Energy). (U.S FIGURES 2009). Amongst these three sectors, buildings including residential, commercial, light commercial and institutional signify for about one third of the total energy consumption compared to other energy-using sectors. It was reported that about 35 to 40% of total energy was consumed in buildings in the developed countries with 50 to 65% of electricity consumption. The rate of building energy consumption in developing countries is also predicted to increase as the nations keep improving their standard of living and quality of life. Buildings are responsible for 40% to 70% of world carbon emissions

Sustainable Development

Sustainable building is not a new style of building. It is a way to think about how we design, construct, and operate buildings. Using the best of traditional approach in logical combination with green materials. The concept of sustainable development is based on three principles: i) Consideration of whole life cycle of materials; ii) Development of use of
natural raw materials renewable energy source; iii) Recyclable product to be used. [Life cycle assessment, LCA]

**Vernacular Architecture and sustainability**

In vernacular architecture, buildings are design with climatic conditions in mind that helped to achieve human comfort by using locally available materials and construction technique. Apart from cost effective and eco-friendly, these materials impart unique character and culture to the space.

**India**

*India is a multifaceted country with huge regional span. India presents an excellent diversity of topography, natural features, cultures, traditions, people, languages, economic features and more. India is divided into six zones based upon climatic, geographical and cultural features namely North Zone, South Zone, East Zone, West Zone, Central Zone and North East Zone. All these zones include 29 states and 7 union territories. Each zone is comprised of certain number of states and union territories.*

North Zone: North zone of India houses the sates of Jammu and Kashmir, Himachal Pradesh, Punjab, Uttarakhand, Uttar Pradesh and Haryana. This zone of India is also the home to mighty Himalayas and other mountain ranges.

![Earthquake damage risk map of India](image1)

![Earthquake damage risk map of Uttarakhand, India](image2)

Figure 1 Earthquake damage risk map of India

Figure 2: Earthquake damage risk map of Uttarakhand, India

Figure 1 shows that the earthquake zoning map of India divides India into 4 seismic zones (Zone 2, 3, 4 and 5). According to the present zoning map, Zone 5 expects the highest level of seismicity whereas Zone 2 is associated with the lowest level of seismicity. And figure 2 shows that Uttarakhand falls in the zone 4, this zone is called the high damage risk zone.

**Literature study – North India**

This literature study covers two types of vernacular practice of the north India. The practice are as follows , i) Dhajji Dewari ii) Kath Kuni.

**1.1.1.1 Dhajji Dewari**

It is noted that 2005 earthquake in Kashmir, India, building performed much better of vernacular practice(Dhajji dewari) than modern structure. Dhajji Dewari technology, uses complete timber frame with masonry framing panel within the frame, forming panels within frame.
Building feature | Description
--- | ---
Typology | The dwelling are of single storey detached houses, gross area of 70 sq.m, gross internal area of 46 sq.m
Structure | RCC foundation and plinth with a superstructure of locally available timber columns and beams.
Roof system | Pitched roofs with rafters and purlins made of locally available slender timbers. Roof covering was done with CGI sheets.
Wall system | Dhajji Dewari system of timber bracing with an infill of stone masonry that is mud plastered
Door window | Opening of timber frames and well integrated into the Dhajji Dewari cross beam bracing system.
Buffer spaces | South facing veranda

1.1.1.2 Kath Kuni

Figure 3 shows traditional multistoreyed structure in Rajgarhi, district of uttarakashi, uttarakhand, india. A large number of intact building of the district is earthquake resistant construction type known as Koti banal. They are quake—proof, survived earthquake, 1991(magnitude of 6.6 on the Richter scale), 1999 and 1720 and 1803.

Building Feature | Description
--- | ---
Typology | Multi- storied detached structures of height varying between 7 and 12 m above the plinth. They have rectangular plan configurations with the length and widths varying from 4-8 meters
Structure | The building rest upon a raised dry stone masonry platform over the foundation made in rubble masonry. In the lower part, the wall consist of a configuration with orthogonally arranged wooden logs interconnected at the junctions by wooden pins/tenons. For the two bottom-most layers single wooden logs while for the upper layers double wooden logs are used. The infill between the logs is furnished with well-dressed flat stones which are dry-packed or by using a paste of pulses (lentils) as mortar. This wooden structure is not used for the upper parts of the wall where the dressed stones have a load-bearing function. The structure is further reinforced by wooden beams which are perpendicular to the
wooden logs at the middle of the walls connecting two parallel outer walls.

<table>
<thead>
<tr>
<th>Roof system</th>
<th>Typically, the roofing span is half of the building width. The roof construction consists of a wooden frame which is expected to act as a flexible diaphragm and is clad with the slate tiles.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall system</td>
<td>50-60 cm thick timber – reinforced stone masonry. The thickness of the walls is determined by the thickness of the two parallel arranged wooden logs.</td>
</tr>
<tr>
<td>Door / windows</td>
<td>A single small door access on the ground floor and relatively small south facing windows floors above with wooden frames and shutters.</td>
</tr>
<tr>
<td>Floor</td>
<td>Wooden beams and planks resting on wooden joists supported by beams or walls.</td>
</tr>
<tr>
<td>Semi-outdoor spaces</td>
<td>The upper two floors have balconies running around the whole building cantilevering from the wooden logs of the flooring system with a wooden railing</td>
</tr>
</tbody>
</table>

**Case study**

A Rural Case Study which was conducted on a village named Jadi, Chakrata Tehsil in Dehradun District of Uttarakhand State, India. It was situated at an extremely earthquake prone zone of Uttarakhand state, India. Two houses were taken in account, *House 1 – katcha houses (traditional shelter)*, *House 2 – Pakka houses (conventional building materials)*.

**House 1 – katcha houses (traditional shelter)**

*House* is a traditional shelter, built in koti banal architecture. figure 4, shows the different elements used in traditional shelter and the material used are deodar wood and stone.

![Figure 3 katcha houses (traditional shelter) showing section and elevation](image-url)
In figure 5, 6 and 7 shows the plans and section, showing that the houses are built in stone filled platform with judicious use of wood. These wood based structures are flexible and better in absorbing and dissipating energy reducing the risk of breakage and collapse. The structure is two storeys high with the linear arrangement of room connected by the internal stair. The ground floor is 1.8m high and use to keep animals. The upper level is of height 2.7m, with all the living areas are provided along the cooking area /kitchen; it helps the surrounding rooms warm during the cool night time. Also, the attic space is provided below the pitched roof covered with shingles / stone tiles. All the wet areas are kept away from the living room. All the habitable space is oriented toward the south, east and west to receive maximum solar heat gain during the day time, which is stored in the thermal mass of the dwelling to keep the interiors warmer during night. The low ceiling height helps to keep the interior of the room warmer. Also this contribute to the low surface to volume ratio of these dwelling units and thus reducing the heat loss from its surface.
Explaining figure 8, 9 and 10.

1. Foundation and plinth-(Stone plinth) the depth of the trench is relative to the height of the structure. For a two storey house, the depth is 0.6 to 1 meter
2. Wall- Wood-and-stone walls) the walls are constructed with alternate courses of dry masonry and wood without any cementing mortar. And if mortar is used it is of lime or mud mortar.
3. Windows- Windows are provided in walls with solid plank shutters on all four sides and are usually very small.
4. Projecting wooden balcony- A typical two storey house with a cantilevered balcony on the top floor. The wooden members supporting the balcony rest on the wall.
5. Roof- The roof structure is constructed out of wooden beams followed by purlins and rafters, topped with slate or wooden shingles.

<table>
<thead>
<tr>
<th>Advantages of vernacular architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>• No external help required Locals can construct their own houses.</td>
</tr>
<tr>
<td>• Time and resource efficiency Wood and Stone are used as an alternative against slow setting mortar.</td>
</tr>
<tr>
<td>• All materials are available in the vicinity of the village Low maintenance Requires very low effort to maintain and repair Structural resilience Non rigid construction helps to dissipate the stresses developed in the earthquake.</td>
</tr>
<tr>
<td>• Resource re-use There is hardly any wastage and since materials don’t deteriorate for a long time and can be reused.</td>
</tr>
<tr>
<td>• Bio degradable materials No synthetic materials are used or fixating materials like mortar are used. Very limited use of metal is seen.</td>
</tr>
<tr>
<td>• Built form and climate Infill traps air within the walls creating an insulation zone.</td>
</tr>
<tr>
<td>• Energy efficient configuration and elements Cubical stacking along contours, fetching maximum sunlight.</td>
</tr>
<tr>
<td>• Slope of the roof allows snow to fall off whereas the flatter part holds some snow which acts as an insulation layer Cattle are kept at the ground floor which keeps the upper floors warm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantage of vernacular architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulty of getting suitable orientation on the hill slopes.</td>
</tr>
<tr>
<td>• Problems of soil erosion and landslides.</td>
</tr>
<tr>
<td>• Restrictions by the forest department.( ban on cutting of the trees).</td>
</tr>
<tr>
<td>• Limitations on the height of the building due to earthquake risk.</td>
</tr>
<tr>
<td>• High cost involved in the site development due to the cutting and the filling process. (hill region)</td>
</tr>
<tr>
<td>• Non-availability and transportation problems of construction.</td>
</tr>
</tbody>
</table>
**House 2 – Pakka houses (conventional building)**

The house number 2 were built irrespective of their climate. The structure is single storey, is built with brick and cement concrete, steel. Planning copied from the traditional building.

![Ground floor plan](image)

**Figure 10** Ground floor plan

**Figure 11** Section through A-A'

![Three dimensional structure](image)

**Figure 12** Showing the three dimensional of studied house

Advantages and disadvantages of pakka house

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Availability of materials.</td>
</tr>
<tr>
<td>• Socially accepted.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Require good workmanship for construction</td>
</tr>
<tr>
<td>• Is very uneconomical, since cost of transportation sometimes makes the product cost double.</td>
</tr>
<tr>
<td>• Do not have any good aesthetic appearances when poorly constructed.</td>
</tr>
<tr>
<td>• Does not show any cultural values.</td>
</tr>
<tr>
<td>• Cause greater footprint in the environment.</td>
</tr>
<tr>
<td>• Materials used in construction are not Earthquake resistant.</td>
</tr>
</tbody>
</table>
• Resources are not useable once demolished and responsible for construction waste.
• Materials used as a whole emit carbon dioxide during manufacture.
• Does not respond to climate and environment.
• Concrete slab have high transmission value, indicating it does not have good insulation property.

Proposed - Sustainability Approach

The present work aims to adopt green building material and modern technology in vernacular, to achieve this virtual (STUDY) house was modelled. It was noted that, the fundamental for the survival of any structure is to ensure a structural equilibrium of flexibility and rigidity. This is especially true in environmentally volatile areas where there are frequent floods and/or earthquakes. The second fundamental principle that needs to be adopted in these areas is to dilute the impact of natural disturbance, rather than having they battle against rigid barriers.

The Study model

The study model in this study was design on the basis of Rural case study conducted on a village named Jadi, Chakrata Tehsil in Dehradun District of Uttarakhand State, India.

The aim is to create a sustainable model based on the vernacular practice of north India. It is noted that this region is in highly earthquake prone zone. Two changelles for this study model was to create sustainable and earthquake resistant model. To achieve this, two types of vernacular practice (discuss above) was studied in deeply. Their best practice methods were noted and are implemented in the proposed study model.

<table>
<thead>
<tr>
<th>Building Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typology</td>
<td>Detached structures Single/Multi- storied of height 3 meter(single storey) above the plinth. Rectangular plan configurations with the length and widths 6 x 10 meters. Have a grid of 2 meters x 2 meters (multiple of 2m as in vernacular structure). As shown in figure 16.</td>
</tr>
</tbody>
</table>

The plan is composed of 5x3 grid of 2000mm. the levels taken for the proposed model is 3000mm. Two proposal plans are made. Floor plans for single storey are shown in figure 17. Second one is floor plan of double storey is shown in the figure 18.
Structure

Structure is a composition of Koti Banal and Dhajji Dewari architecture. Thus making a composite structure. The building rests upon a raised dry stone masonry platform over the foundation made in rubble masonry. The wall system follows Dhajji Dewari system (Figure 18) of timber bracing with an infill of stone masonry that is mud plastered. The roofing system is hip roof as it becomes the part of the wall bracing and the structure act as a whole and flexible.

Foundation

The foundation made in rubble masonry.

i) Depth and width: foundation is 900mm deep in the soil. With a width of 600mm, it should be at least 600mm deep from top soil.

ii) Plinth of 300mm on the top of foundation. To keep base member away from ground. The outer part of the top surface of plinth with a slope towards outside to drain water away from the base plate.

iii) A void is made of 25 mm in which a Galvanized anchor rod is placed and the left space is filled with the mortar. This void should be made 250mm – 300 mm away from corner.

Roof system

Roofs with four slopes (hipped roofs) are stronger than roofs with only two slopes (gable roofs) because the hips act as braces. Gable roofs need additional internal bracings. Moreover, the gable walls are at risk of falling over during an earthquake. For spans up to 4.5 meters, simple trusses can be used. For larger houses the roof structure should be supported by posts on the ground floor, at a maximum distance of 4.5 meters. The study model span is 10 meters the roof is supported by post at 4 meters interval.

Door / windows

A single small door access on the ground floor and relatively small south facing windows floors above with wooden frames and shutters.

Floor

The floor is divided into two: base floor and finished floor. Base floor is consist of rubble stone masonry. the finish floor is of mud. The proportion taken for this one – third clay ,two- three sand with pines needles or straw. The straws or pine needles not only helps in resisting crack which is generally to occur if the mud mortar dry but also , help to make the whole mixture flexible.

Wall system

The wall system is Dhajji Dewari system of timber bracing with an infill of stone masonry that is mud plastered.

• Main frame is 3m x 3m. The base frame member have a cross section of 100 mm x 100mm. for double storey have plate cross section taken should
• Secondary frame division, the cross section taken 50x 100mm.
• Final sub-division, the cross section taken 25x 100mm, is the placed diagonally. Forming a triangular space.

These triangular forms are now filled with the three-fourth stones, one-fourth mud and stone flakes. Finished with a mud plaster (one-third clay, two-three sand with pines needles or straw.)

Figure 18: Dhajji Dewari wall detail
Figure 19 showing timber braces
Figure 20 showing the space between braces is filled with stone and stone is again secured by wire mesh.

Figure 21: 3d model of the proposal for single story
Figure 22: 3d model of double story

Finished surface with the Earth plaster
Roofing slate tile
Stone is filled in between the bracing
Material
• Stone - Stone for wall / slate tile for roof covering
  All natural stone slabs are 100% recyclable with endless ways to re-purpose the material.
• Wood – for making frame (the dimensions are already explained above)
  Using wood as a material in building construction can have significant environmental
  benefits. Manufacturing wood for construction is less energy intensive than other materials.
• Rammed earth for plaster and flooring.
  Mud construction also provides natural air conditioning which provides cool air from the
  massive walls. The mud – house uses minimal energy, is comfortable year round.

Conclusion
The comparison between the vernacular and the modern examples in their building
materials, can achieve a satisfactory result on reducing (59.77%) of the total CO2 emissions.
Vernacular buildings require similar amounts of energy and result in similar levels of CO2
emissions, both being much more than the equivalent values for modern building.

Difference on the term of environment impact

<table>
<thead>
<tr>
<th></th>
<th>Vernacular</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>Locally available</td>
<td>Availability is limited .Materials</td>
</tr>
<tr>
<td></td>
<td>No cost of materials</td>
<td>cost is very uneconomical</td>
</tr>
<tr>
<td>Transportation</td>
<td>No transportation charges.</td>
<td>Transportation charge can double</td>
</tr>
<tr>
<td></td>
<td>Locally available.</td>
<td>the cost the cost of materials</td>
</tr>
<tr>
<td>Reusability</td>
<td>Can be reuse</td>
<td>Cannot be reused</td>
</tr>
<tr>
<td></td>
<td>Does not generate waste</td>
<td>Responsible for construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>waste</td>
</tr>
<tr>
<td>Pollution</td>
<td>Does not cause pollution</td>
<td>Emit carbon dioxide during its</td>
</tr>
<tr>
<td></td>
<td>Less environmental footprint</td>
<td>production and demolishing.</td>
</tr>
</tbody>
</table>

Differentiation on the terms of Sustainability

<table>
<thead>
<tr>
<th></th>
<th>Vernacular</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical</td>
<td>The traditional architecture of</td>
<td>1. Not cost- efficient.</td>
</tr>
<tr>
<td></td>
<td>Uttarakhand, India is relevant</td>
<td>• These materials have high</td>
</tr>
<tr>
<td></td>
<td>even today due to its following</td>
<td>embodied energy and cause lot of</td>
</tr>
<tr>
<td></td>
<td>features</td>
<td>pollution during manufacturing and</td>
</tr>
<tr>
<td></td>
<td>1- Mostly wood and stone were</td>
<td>transportation, and are mostly</td>
</tr>
<tr>
<td></td>
<td>used for construction</td>
<td>inappropriate to the context of hill</td>
</tr>
<tr>
<td></td>
<td>2- Cost-efficiency Stability</td>
<td>settlements.</td>
</tr>
<tr>
<td></td>
<td>• Mud - easy availability, good</td>
<td>• Cement – costly due to lack of</td>
</tr>
<tr>
<td></td>
<td>insulation and the good binding</td>
<td>availability and transportation</td>
</tr>
<tr>
<td></td>
<td>properties</td>
<td>charge in higher altitude.</td>
</tr>
<tr>
<td></td>
<td>• Wood - the deodar wood and</td>
<td>• Bricks – for the construction of</td>
</tr>
<tr>
<td></td>
<td>other mixed forests were easily</td>
<td>walls hence, costly due to lack of</td>
</tr>
<tr>
<td></td>
<td>available. Wood is used to impart</td>
<td>availability and transportation</td>
</tr>
<tr>
<td></td>
<td>stability to tall structures.</td>
<td>charge.</td>
</tr>
<tr>
<td></td>
<td>• Stone – remains in use but its</td>
<td>• Aggregates – course aggregate for</td>
</tr>
<tr>
<td></td>
<td>usage is restricted to the plinth to</td>
<td>the construction of plinth and the</td>
</tr>
<tr>
<td></td>
<td>give strength and in some places</td>
<td>need of fine aggregate for the</td>
</tr>
<tr>
<td></td>
<td>used for wall construction.</td>
<td>various purpose of construction</td>
</tr>
</tbody>
</table>
Environmental

- Vernacular technique generated by the understanding of nature
- Non-engineered indigenous construction techniques are developed with local materials, have good climatic response, maintain indoor comfort conditions
- Have very good response against earthquakes.

Social

- Socially not accepted
- Even in the village people are demolishing these houses and going for conventional building

Massive development with contemporary materials results in:
- Pollution, loss of vegetation, increase in soil erosion,
- Lowering of water table, flooding,
- Change in micro climate and increase in occurrences of instability, which cause severe damage to sensitive and fragile environment in and around hill settlements

- Socially give status to people.
- Brick concrete and glass construction give status to the society.

**Environmental sustainability**

The house is designed to reduce greenhouse gas emissions, save water and energy and reduce waste. During construction and the house's lifetime.

**Social sustainability/universal design**

The house is designed to prevent injuries through built-in safety features. It has improved the occupants' sense of security. Features are also used to provide flexibility and comfort for people of varying abilities and at different life stages.

**Economic sustainability**

The house is designed to save money during construction and over the lifetime of the house. Careful planning avoids the need for major future renovations and reduces costs associated with energy use, water use and maintenance.

The impact of globalization has threatened traditional and cultural values by the forces of economic, cultural and architectural homogenization. This has brought disregard for traditional environment and often considered as a symbol of poverty and backwardness. In the race of modernity, values, beliefs, culture are removed from the society. The research can give vision to policy makers, planner, architects to look into the traditional crafts and trades, understanding the vernacular traditions and incorporating them in the contemporary planning.

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A framework for determining the most effective parameters for optimal life cycle analysis in the early stages of building design

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Abstract: Analysing a building’s environmental impacts through its whole life cycle requires a very complex method to be applied by designers. This is especially true at the early design stage, where most of the critical design decisions for environmentally friendly buildings are made. This complexity arises from a variety of areas, such as: unavailability of required databases; requiring a vast amount of data and details, including uneven levels of uncertainty at different phases; the effects of diverse external parameters such as climate; and, the lack of expertise in the building design area.

The main question addressed by this paper is: How can building designers be assisted to make better, more environmentally friendly life cycle decisions in the early design stages of a new project? The paper suggests that a prioritisation of the most effective parameters for minimising building environmental impact in each respective phase of a building’s life cycle can assist designers in making better decisions upfront that lead to greater benefits across the whole life-cycle. The paper puts forward a framework for determining these parameters by identifying the key difficulties and proposing the possible solutions. Addressing these difficulties leads to a proposal for a basic tool for designers, which will help to ascertain the most effective parameters for optimal life cycle analysis. Inputs, system function and outputs of the tool are defined as the results of this research.

Keywords: Life Cycle Assessment (LCA), early design stage, effective parameters

Introduction

Minimizing impacts on the environment is an important goal for the building sector (Thormark, 2001). Buildings not only impact the environment through energy consumption and greenhouse gas emissions, they also negatively impact aspects such as water use, waste generation and resource depletion (Stephan et al., 2013). Rapid urbanization in developed and developing countries is expected to increase demand for new buildings and more comfortable living environments and therefore further exacerbate these impacts (Ortiz et al., 2009). Buildings with the direct and indirect impact on the environment cannot be sustainable except if they are analysed over their whole lifetime. Together, the construction and operation of buildings are responsible for significant energy consumption and consequential generation of greenhouse gas (GHG) emissions. Existing buildings consume more than 40% of the world’s total primary energy and account for 24% of global carbon dioxide (CO₂) emissions (IEA, 2008). The residential sector is the most energy-intensive, consuming about 60% of the overall energy used by the buildings (BREE, 2014). The importance of considering the life cycle environmental impacts of a building has been elaborated by several studies (Fay et al., 2000, Thormark, 2002, Dixit et al., 2010, Monahan and Powell, 2011). They have shown that the environmental impact of initial construction can be just as significant as those affected by their operations.

Rating systems for designing high-performance and sustainable buildings are becoming more and more popular. However, in order to account for the overall impact of building construction and use on the environment, comprehensive methods such as Life Cycle Assessment (LCA) should be applied (Trusty and Horst, 2002). LCA is a method for the systematic analysis of environmental impacts of the products or processes over their life
cycle. LCA is often considered as a “cradle-to-grave” approach to the evaluation of environmental performance. Cradle-to-grave analysis includes all phases of a product’s life: the extraction of raw materials, component’s and related materials production, their use and maintenance, and waste removal or recycling (Cabeza et al., 2014, Klöpffer, 2014). A study of a residential building in Australia (Crawford, 2014) shows that operational energy accounts for only the 40% of total building energy demand, while the remaining 60% is represented by embodied (initial and recurrent) and demolition energy. However, these ratios are deemed to change when multi-storey buildings constituted of multiple dwellings, due to the increased impact of structural, envelope, and building services’ sub-systems on overall Life Cycle Energy demand.

The most important decisions regarding the minimization of the life cycle environmental impacts and energy consumption are made at the beginning of the design process. Therefore, earlier assessment could effectively influence minimising the life cycle environmental performance of a building (Figure 1). However, this rarely occurs in practice as LCA is too complicated to be applied by designers at the early stage.

How then can building designers make more environmentally friendly life cycle decisions at the early stage of the design of a new project? This study attempts to answer this question by identifying the key difficulties and proposing the possible solutions to simplify the application of an LCA method. Addressing the identified difficulties leads to a proposal for a basic tool for designers to apply at the earliest stage to determine the most effective parameters to minimise a building’s life cycle environmental impact. It is this selective prioritisation and concentration on key effective parameters that allows for the simplification implied by this study. Inputs, system function and outputs of the tool are defined as the results of this research.

![Figure 1: Influence of design decisions on life cycle impacts and costs (UNEP, 2003)](image)

**How can the building designers be assisted to make better, more environmentally friendly life cycle decisions in the early design stages of a new project?**

Application of LCA method at the earliest stage of building design can lead designers to make better environmentally friendly life cycle decisions. Investigating the most effective parameters for the building environmental performance at each stage of a building life cycle
could significantly minimise its impact on the environment in relation to the specific character of each project. However, it is not possible for designers to achieve this goal without application of complicated analyses which are very time consuming and costly at the early design stage.

**What are the difficulties?**

A multitude of interrelated parameters affect a building’s Life Cycle Assessment (LCA), making it too complex for designers to base decisions on, particularly at the early design stage. Many attempts have been made to quantify the total environmental impacts associated with buildings through their life cycle. However, quantification methods are not generally employed by building designers at the early design stages when they may be of most benefit. The availability of data in the initial stages of design is a major difficulty for designers. A huge amount of data and a certain degree of expertise in the field are required for LCA. Furthermore, building plans, including details of external walls, partitions, slabs, roof, and the selected cladding system, needs to be well defined to accurately perform LCA. Because architects and engineers have limited expertise in LCA and the building form and fabric are fluid at the early design stage, most design decisions at this stage are based upon on the designer’s experience rather than quantitative indicators.

Inventory assessment of building materials and the process of construction and demolition are the main aspects of the environmental impact assessment. However, a major difficulty with this kind of analysis is that the material production processes are not always standardised due to the contextually specific aspects of each building. The availability of assessable information about the environmental impacts of the production and manufacturing of construction materials, the actual process of construction and demolition are limited (Ramesh et al., 2012). In addition, values of embodied energy and equivalent emissions of carbon vary by country due to the energy mix, transformation processes, efficiency of the industrial and economic system of the country, and the variability of these factors over time, making calculation even more difficult (Sartori and Hestnes, 2007).

The other important criteria for decisions made from a life cycle perspective involve ensuring that a solution to reduce energy consumption for one life cycle stage does not increase overall life cycle energy demands. Results from previous studies of life cycle energy requirements demonstrate that a particular material or assembly may perform differently when applied in a different situation. For instance, materials with low initial embodied energy do not necessarily have low life cycle energy (Utama and Gheewala, 2009, Crawford et al., 2011). The review of some LCA studies of building materials and products (e.g. Asif et al., 2007, Kofoworola and Gheewala, 2008, Monahan and Powell, 2011, Zabalza Bribián et al., 2011, Monteiro and Freire, 2012, Crawford, 2013, Thiel et al., 2013, Dodoo et al., 2014, Lee et al., 2015) shows that these studies used different assumptions, materials, databases and analysis method. It is therefore difficult to draw comparisons among the studies and find generalisable design principles that could be employed by designers at the early design stage.

To have a better understanding of these difficulties and to find solutions, the identified difficulties are categorised in three main groups in this study (Figure 2):

- Data related
- User related
- Early stage related (early design stage)
What are the solutions?

To address the identified difficulties, the following potential strategies are proposed:

- Limiting the effective parameters on the LCA
- Considering the most influential building elements in terms of their environmental performance
- Defining a system boundary
- Considering the specific character of each project
- Using certain and available data
- Classifying the data
- Generalising results from previous LCA studies
- Designing a framework to investigate the most effective indicators regarding building environmental performance

To specifically address each of the difficulty categories, solutions are proposed in three main groups.

Solution to data related difficulties:

Regarding the LCA simplification and also limiting the most effective parameters, the building envelope is considered as the most effective building elements in terms of its environmental performance. A building, as a unique and complex system, includes various sub-systems. The building envelope plays a crucial role in the interaction between the building and the environment. It is known to be responsible for more than 50% of the embodied energy contribution in residential buildings (COAG, 2009). Envelope related energy demand is determined based on the assumption that heat transfers by thermal transmission through the building envelope and by solar gains. Most of the envelope-related parameters have an influence on the thermal balance in buildings. Results show that
there is a strong correlation between envelope related energy demand and the operational energy demands of buildings (Granadeiro et al., 2013). The significant impact of building envelope design on its environmental performance has been presented by several studies (Cheung et al., 2005, Ramesh et al., 2011, Zabalza Bribián et al., 2011). For instance, one study (Cheung et al., 2005) shows how the improvement in building envelope design positively affects the annual required cooling energy for high-rise apartments in hot and humid climates. Various building envelope components from an energy efficiency and saving perspective have been reviewed by (Sadineni et al., 2011). Hence, the operational energy reduction requires the use of materials or layers of materials in the construction of the building envelope that have low thermal conductivity and significant heat capacity (Ramesh et al., 2011).

Solid envelope layers and choice of materials for a building’s external walls like thermal insulation plus window systems are known as the most effective parameters impacting operational energy. Because these materials may negatively affect the total life cycle energy demand of a building by increasing the embodied energy, if designers are to minimise the life cycle energy demands they need to understand the individual impact of each variable on energy performance as well as the dependencies between them in order to select appropriate materials/systems at the early design stages. However, because of the complexities of determining environmental impact and uncertainty about the later stages of a building’s lifespan, introducing an environmentally friendly design approach that takes into consideration every stage of building’s life cycle is rarely focussed upon by designers at the building’s early design stage. Transparent and opaque parts of a building envelope impact differently on its life cycle environmental performance. The level of effectiveness of these parameters on the building life cycle environmental performance changes due to specific condition of each project.

Reviewing the LCA studies of window system led this research to select the following parameters as the most effective indicators of window system on minimising buildings environmental impact through their whole life cycle:


Material selection and design strategies for different layers of opaque envelope like external cladding, insulation, frame and internal lining are considered to be effective indicators for the building’s life cycle performance. (Basbagill et al., 2013, Cheung et al., 2002, Himpe et al., 2013, Eskin and Türkmen, 2008, Nedhal Al-Tamimi, 2012, Ramesh et al., 2012, Iddon and Firth, 2013, Rauf and Crawford, 2013).

**Solution to user related difficulties**

Lack of LCA expertise of building designers, as well as the requirement for a huge amount of data and uncertainty about the required data, negatively affects the early stage design decisions in terms of a building’s environmental performance. Defining a system
boundary is a solution to minimise LCA data requirement at the early design stage. It helps designers to use the most available and certain data for making design decision at the early stage. Building designers at the early design stage of each project have access to detailed information about the climate, location and type of the building. Moreover, they are able to make reasonably reliable assumptions about the building lifetime. These four parameters which are defined as specific character of each project affect externally on a building life cycle environmental performance. Climate, location, building type and building lifetime are selected as a system boundary in this study regarding their different impact on different phases of a building life cycle including construction, use, end of life and transportations. The effectiveness of these parameters varies from highly to minimally effective.

**Climate** has a significant impact on a building environmental performance as it directly affects a building’s annual heating and cooling energy loads. It has a large impact on a building’s operational phase, and there is a strong relationship between climate and the effective indicators of the building life cycle environmental performance. Climate is one of the most specific factors considered by building energy efficiency regulations around the world (Crawford et al., 2016). Climate has a different influence on each phase of the building life cycle in terms of energy consumption and emissions. In the construction phase, climate significantly affects the choice of material mass in regard to maintaining indoor environmental comfort. Climate also impacts on the construction site operational energy demands. The need for different packaging and storage methods of materials are also related to the climate condition. The installation time and systems in the construction phase is another parameter which is affected directly by climate. Climate as an external parameter has the most influence on the operational phase of the buildings. It directly affects the summer and winter operating schedule, annual heating/cooling energy demands, lighting energy loads and maintenance code. Climate conditions affect transportation types and durations which could change the environmental impact of this phase. It also has influence on product service life and thermal loss/gain during the building operation.

**Location** as an external parameter could influence the building environmental performance analysis in two different ways. First, the country location of the project impacts on the LCA results considering different life cycle inventory (LCI) databases, various regulations, primary energy types, commercially available materials, occupancy pattern and current building practice. Second, the location of the construction site has an influence on the orientation and neighbouring context affects the building’s LCA results. Location affects the building’s embodied energy in terms of distance to material suppliers and manufacturing facilities and therefore transportation impacts. The building’s embodied energy is affected by the source of electricity used in different country locations (Salazar and Sowlati, 2008). Moreover, the life cycle environmental performance of buildings and their components are affected by different manufacturing practices, energy consumption patterns, transportation and logistics systems, and electricity generation and distribution in different geographic locations (Azari, 2014).

**Building type** significantly affects the operation of the building. The importance of operational parameters varies in different building types. For example, lighting energy demand in office buildings is considered a highly influential parameter. The operating schedules, operating patterns and the utilization of air conditioning system and other factors related to the building type affect LCA results.

**Building lifetime** has an influence on the maintenance phase of buildings, and consequently the amount of building life cycle embodied energy is affected by the building
lifetime as an external parameter. The significance of material service life, material reusability and recyclability, differs relative to building lifetime.

Solution to Early Stage Related Difficulties

Design decisions in terms of optimising a building life cycle environmental performance should be taken at the early design stage to have the most benefit. Dependency of LCA on various possible methods, phases and impacts, beyond different levels of uncertainty in various LCA phases, prevent designers from making environmentally friendly design decisions at this stage. A basic tool is proposed by this study as a solution to address these early stage related difficulties. It is intended to assist designers to simply investigate and identify the most effective parameters for minimising buildings life cycle impact. A user-friendly tool would thus assist designers make optimised design decisions at the earliest stage without need of complicated analyses and huge amount of data.

Designer-Friendly Tool for the Early Design Phase

The process used to design the user-friendly tool and its technical descriptions are presented in this section. The tool is designed in three main parts: inputs, system functions and outputs. It is designed to generate information in connection with each specific group of input data using the defined rules.

Inputs

A system boundary defined to minimise the data requirement for investigating the most effective parameters on buildings life cycle environmental performance. The four external parameters are employed as input data. They define the specific condition of each project and designers have the required information at the earliest design stage. So, designers input the data related to the climate, location, building type and building lifetime of each project. This information can be used in very detailed format to generate comprehensive and very accurate results. But, in the space of this study, designers select from a few limited options (with the significant impact) listed as subsets of each category. Users input data by selecting among subsets as follows:

- Climate, designer selects from: Hot-Dry, Hot-Humid, Cold-Dry, Cold-Humid, Moderate/heating dominant; Moderate/cooling dominant.
- Location, designer selects from: Urban, Remote
- Building type, designer selects from: Residential, Office
- Building lifetime, designer selects from: Short, Average, Long life.

System Function

A knowledge-based system (KBS) is used for designing the basic tool in this study. It contains specific knowledge in the form of rules which enable system to generate outputs based on the designer’s inputs. The relationship between the most effective parameters (from the solution to data related difficulties) on the building life cycle performance and the external parameters (the solution to user related difficulties) is determined in terms of common rules for the KBS. The inference engine uses the information from the knowledge to derive the conclusion. Figure 3 and 4 are examples of simple algorithms which provide the essential knowledge for the KBS. Each cell (e.g. WCh) contains a number of recommended choices for designers to select from intended to optimise their design or material selection at the earliest stage in relation to a building’s environmental performance. One possible
method of generating the knowledge for the system is by extracting common rules from results of previous LCA studies. This is neither a comprehensive nor highly accurate method, but can provide the required common rules without need of complex quantifications. (A document analysis method for extracting common rules from the results of previous LCA studies was applied by the author in another study which is in progress. Discussing the method of generating data for the system is not within the scope of this paper).

**Outputs**

The most effective parameters for optimal life cycle analysis in the early design stages of building are the outputs of this system. Outputs are in format of a small number of recommendations for design and material selection for the building’s envelope which are expected to minimise the building’s life cycle environmental impact. Outputs are generated in two groups, one for window design and the other for solid envelope design.

![Figure 3: Window system most effective parameters](image1)

![Figure 4: Solid envelope most effective parameters](image2)

**Conclusion**

Using LCA methodology to minimise a building’s life cycle environmental impacts is presently too complicated for designers to use to make environmentally friendly design
decisions at the early design stage. While significant research has been conducted on the environmental impact of buildings, the knowledge about the type and quantity of information from quantitative LCA models is still limited. This information is not available when designers make strategic design decisions at the early design stage that will influence the whole lifetime environmental cost of the building. Designers are not able to use the results of previous LCA studies as guidelines for the early stage design of new projects for reasons including: the variety of methods and phases in their analyses; the specific character of every project; the different goal and scope of every project; the use of different databases, different assumptions, estimations and interpretations.

Three groups of difficulties of LCA application at the early design stages were analysed in this study. This has led the research to propose three groups of solutions to determine the most effective parameters for optimal life cycle analysis in the early stages of building design. The outcome of this study is the proposal for a method for designing a user-friendly tool to assist building designers to investigate elementary heuristic principles for minimising a building’s life cycle environmental impact at the early design stage.

SHGC: Solar Heat Gain Coefficient   VT: Visible Transmittance   DG: Double Glazed

- Reduce the WWR increase the lighting load and decreases the cooling load.
- Windows elements are responsible for the highest production related CO₂ emission factors particularly aluminium frames.
- The influence of the operation mode of air conditioning system, the orientation of the outside window, and the glazing types of window can be regarded as a reference factors for the WWR when designing residential buildings.
- Service life of frame materials identified as the most important factor regarding their environmental impact.
- Increasing the efficiency of artificial lighting system decreases the value of WWR regardless of the locations and orientations.

Figure 5: Tool outputs for selected factors by user (inputs) for Window system
In general, passive design strategies performed slightly better for longer lifetimes and standard design strategies for shorter lifetimes, because the relative importance of the building services decreased for shorter lifetimes.

For same thickness of insulation, LCE savings are much more with roof insulation than wall insulation.

Figure 6: Tool outputs sample for selected factors by user (inputs) for Solid Envelope

References


A Conceptual Model for Climatic-responsive Vernacular Architectural Forms

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Abstract: Indoor lighting, in terms of its spatial coverage, spectral range and extent is closely associated with occupants’ behaviour, yet little is known about its links with now-abandoned 19th century vernacular architectural forms of dry-and-arid climates in central Asia. Sustainable use of energy for domestic purposes is a critical component of the resilience of urban systems to urban sprawl (and escalating energy demands), mineral resource shortage and changing climate. Domestic energy use is a function of occupants’ behaviour in adjusting themselves to space through movement, which is driven by interrelated light-space-time. A better understanding of such interactions, in the context of energy efficient Iranian vernacular architecture can allow the adoption of traditional styles in design of contemporary indoor living spaces, thereby indirectly influencing occupants’ lifestyles towards lesser use of artificial lighting and energy conservation. It is in trying to understand how vernacular style can be turned into purposeful action that each core domain of vernacular architecture, and the dynamic of light and human through them, should be determined and brought to bear. In doing so, we present a conceptual model, built through field observations - of five three historical buildings in Kashan, Central Iran - interview and archival studies. The model informs on how occupant’s perception of space and response varies with time, space configuration and lighting levels.

Keywords: Daylight, Human, Interior Space, Vernacular, Perception, Energy, Behaviour

1. Introduction

The global urban sprawl, rapid industrialisation, growing reliance on energy delivered mainly through fossil fuels and modern-day consumption habits continues to strain our energy resources. Unwelcomed environmental impacts of unsustainable exploitation of earth reserves (in form of emissions and extreme climates) and the interlinked uncertain security of supply necessitates policy-makers to work towards balancing the supply and demand in at domestic levels. Domestic energy use is a function of occupants’ behaviour in adjusting themselves to space through movement, which is driven by interplay among light, space, and time. A better understanding of such interactions, in the context of energy efficient Iranian vernacular architecture can allow the adoption of traditional styles in design of contemporary indoor living spaces, thereby indirectly influencing occupants’ lifestyles towards lesser use of artificial lighting and energy conservation.

People are not inert recipients of the environment; they interact with environment in an effort to optimize their living conditions (Humphreys, 1995). Environmental conditions affect human’s activities, physical and mental state (Leaman and Bordass, 2000). Light, a key environmental element, has a pivotal effect on human’s perception of space. Light transforms the spatial context and facilitates the establishment of relationships between occupants and their surroundings. Light is connected to time, and has, intrinsically, the features of movement, sequence, and variation in every moment. The role of natural light in human-environment interaction has been the subject of much debate and once fully established can enable an integrated systems approach to the multi-functional provisions of the environment to be adopted for future homes (Fitch, 1972) and will offer a chance to restore the degraded symbiosis between the nature and the built environment.
This paper investigates light and shadow and their implications on architectural design and occupant’s behaviour through an interpretive, archival, and field study. This contribution will revisit the early Persian architectural designs for dwellings and investigate occupant’s interaction with environment in semi-arid climates, that is generally sunny and dry year-round. With the main emphasis on the vernacular residential buildings dated back to the 19th century, where natural light was principally exploited as the main source of energy, this paper provides a new understanding of the behaviour of occupants and their daily activities adjusted to timed movement of sunlight. It explores vernacular architecture from an ethnological perspective, behaviour, and lifestyle of occupants to seek their possible adoption in future buildings to enhance the interaction between human and space which surrounds them that contributes to comfort and better use of domestic energy. A conceptual model is built which relates the position of sunlight in the vernacular houses and occupants’ movements during day. The findings from this work will offer a re-conceptualisation of future living spaces that benefit in making spaces more adaptable and resilient.

2. Light and Urban Space Interplay

Links between daylight and energy conservation has been broadly studied, so too the psychological and physiological implications of ‘managed’ natural light (Ander, 2003, Amundadottir et al., 2017, Custers et al., 2010, Heschomg, 2002, Konis, 2017, Littlefair, 1990, McKennan and Parry, 1984, Ne’eman and Hopkinson, 1970, and Veitch et al., 2008). Managed daylight can improve occupants’ mood, awareness of space, productivity and mental health and reduce stress and anxiety. Prior to 1940s, daylight was the primary light source in buildings. Today, electricity is vastly utilised to satisfy most of the occupants’ indoor lighting demands. Recently, energy and environmental concerns have attracted the attention of built environment researchers working on daylighting and its potential economic benefits (Bodart and Herde, 2002, Hunt, 1979, Hee et al., 2015, Ihma and Krartic, 2009, and Pellegrino et al., 2017). The previous research has mainly been driven by the resilient and renewable sources of domestic energy agenda, but also has attracted the attention of other disciplines in exploring links between natural light and human body-behaviour-perception as a function of architectural forms in a variety of spaces including offices, schools, retail, health care facilities and industrial settings.

The Persian traditional architecture exploits the natural light to form and shape integrated interior spaces (Pirnia, 1992). A wealth of studies is available in literature on the use of daylighting in vernacular buildings of Iran in functional, decorative, and spiritual contexts. The symbolic and metaphorical aspects of light and its interplay with the Iranian ideological views are discussed in Ardalan and Bakhtiar (1973), Ahani (2011), Arjmandi (2010), Ayvazian (2004), Bemanian (2011), Corbin (1993), and Mahvash (2006), Javani et al. (2010). Daylighting strategies in Iranian architecture, especially in traditional houses in hot-and-arid climates, are explored in Moosavi (2014), Maghsoudnia et al. (2015), Nabavi et al. (2013), and Panahi et al. (2013). Chandel et al. (2016) presented a state-of-the-art review of links between energy efficiency and vernacular lighting. Implications of openings and consequent spatial qualities through varied levels of luminance were studied in Arjmandi et al. (2010), Reinhart and LoVerso (2010), and Vanhoutten et al. (2015).

Nevertheless, a comprehensive and structured approach in the study of light in traditional Iranian architecture and its association with occupants’ response has to-date received little attention. The implications of presence, absence and changing patterns of
light on people mobility and adjustment has remained a matter of dispute. The adoption of vernacular forms in contemporary time has declined, if not fully abandoned. This can probably be due to limited available space per head on urban sprawl and commercial pressures on mass construction, yet lessons from a systematic study of traditional systems can facilitate exploitation of natural daylight energy and in this, contribute to the sustainability agenda.

3. Benchmark Buildings and Methodology

3.1 Benchmark Buildings

A rectangular polygon accommodating 3 historical courtyard houses was adopted for this study. The polygon was located at the heart of Kashan City (BWks climate – see 3.1.2 for details), 220 km south of the Iranian Capital, and approximately sizes 950k m². At the north west and north east corners, the site is bordered to 33°58’51.0”N 51°26’47.5”E and 33°58’33.7”N 51°26’05.3”E, respectively. The polygon is bordered to 33°58’13.4”N 51°26’19.1”E from south west and 33°58’24.7”N 51°27’03.3”E from south east.

3.1.1 Historical Background

Kashan is within the highly urbanised Isfahan metropolitan county of Iran. The remainder of the vernacular urban fabric of Kashan dates to developments during the Seljuk (early 9th to late 10th century i.e. 1037-1194) and Safavid eras (early 16th to mid-18th century i.e. 1501–1736). More recent buildings data back to the 19th century (Qajar era). That architectural fabric then began to decline during the 20th century Pahlavi era. Buildings are built with masonry mud or baked brick. The three historical buildings used in this study are: A. Tabatabaei House (N 33.97478 E 51.43918), built in the early 1840s; B. Bani Kazemi House (N 33.976126 E 51.443338) built in 1820s; C. Abbasian Mansion House (N 33.976326 E 51.440235) built in 1870s.

3.1.2 Location and Climate

The Köppen classification suggests four climatic zones for Iran: hot and humid (A), hot and arid (B) - representing 60% of Iran’s landmass, mild and humid (C), and cold (D). The climate class B breaks down further into desert hot-arid (BW) and steppe hot-arid (BS). These collectively form four subdivisions of BWs, BWks, BSks, and BSKs; ‘s’ refers to dry summer, ‘h’ to hot and ‘k’ to cold. Kashan, the study site, fits in the BWks mesoclimate class. The region is acknowledged for the straight and rather strong sunlight radiation year-round (Figure 2a), cold and dry winters, and warm and dry summers (Figure 2b). The maximum temperature can reach levels as high as 45 Celsius degrees over hot seasons and between 20 to 30 Celsius degrees over cold seasons. Sharp variations in temperature between day and night time is not uncommon to the region. The relative humidity varies between 30 to 60 percent (Also see Koch-Nielsen, 2013). To tackle the high intensity of sunlight, local architects tend not to allow the direct light into interior spaces through making use of ‘eluding’ components. Interior space is illuminated through the reflected light from mirror works, mosaic works or water surface. Direct sunlight is allowed in only through a limited number of openings and after passing through wooden/stone latticed windows covered with coloured glasses.
Figure 1. Plan view of the three study buildings - [a], [d], [g]: plan view of the three study houses i.e. Tabatabaei, Bani Kazemi, Abbasian; [b], [e], [h]: the three conceptual interior space domains based on daylight intake; [c], [f], [i]: seasonal comfort zones (based on archival studies, observations, and processed plans in Farokhyar, 2013)
Buildings are commonly rectangular and striking North West (NW) to South East (SE). This axis arguably allows the best position, supplying just enough shade in summer days and heat over winter (Pirnia, 1992). The majorities of traditional buildings look inwards. The entire space is arranged around an open, rectangular courtyard that connects (i.e. effectively bridges) different elements of the house. Distributing built spaces around the central courtyard should improve the indoor air quality and daylighting.

Figure 2. Variation throughout a year of [a] temperature, radiation, and total daylight [b] relative humidity and mean precipitation; stereonet projection (equal area Great Circles and Poles) representing the hourly position of sun throughout a day over [c] summer warm season (21 June) [d] winter cold season (21 December) – developed by authors

3.2 Methodology

Archival desk study is first used at scoping phase to better understand the harmonised space - human - environment architectural systems, and to formulate questions to be posed to a group of interviewees. Walk-over survey i.e. field investigation is then pursued to refine the findings through observation. Six standard questions are designed and provided to the interviewees. Eleven interviews were recorded, compiled, and followed by a short question and answer session to build on evidences and clarify points where needed.

A range of former/current residents and urban design practitioners were targeted for interviews: two senior citizens (who used to live in one of the study buildings during the 1940-50s), two current residents in courtyard buildings within the study polygon, one architect, two psychologists (with an interest in interaction of light and human), two
The adoption of such a diverse group is consistent with the diversity of disciplines involved in urban interior design of responsive systems. Current resident interviewees were asked to fill in a daily logbook, mapping out their movements and activities in a typical June (representing the warm season) and December (representing the cold season) day. They were asked to make the least possible use of electricity/heating throughout the period of study day and adapt their activities to natural daylight. The interview questions are listed below:

(a) Explain the daily activities and movements of occupants in relevance with time and ambient temperature, throughout a typical day

(b) Could seasonal thermal gradients have a detectable effect on user’s perception of space and consequently movements?

(c) On the provided plan view of three study buildings, can you relate time with occupants’ common and individual activities?

(d) How contentment relates to the thermal and visual comfort, in the context of the study buildings?

(e) How the architectural forms relate to the wind and light perception, in the context of the study buildings?

(f) How wind and light perception relates to occupants’ behaviour and their choice of space, in the context of the study buildings?

(g) Could the heating and electricity energy supply in the historical buildings combined with occupants’ modern-day demands promote or hinder the use of managed natural daylight to address part or entire demands of occupants to their thermal and visual satisfaction?

4. Vernacular Structures: Observations and Analysis

The study houses shared the typical 19th century Isfahani architectural form in consisting of two internal and external quarters. The main components include: entrance, central courtyard (pool and garden), Eivan and rooms (reception rooms, living rooms, private rooms, kitchen and services (see Pirnia, 1992). Figure 3 illustrates the plan drawing for House ‘a’ i.e. Tabatabaei House.

The entrance (vestibule) is an octagon or semi octagon space that mainly directs the access to central courtyard. Corridor (Dalan) is a narrow passage that guides the entrant from porch to the yard. This maze corridor provides privacy to the house. The central courtyard (Hayat) is an open-air common space mainly for socialising and reception. The planted greenery (cooling media on evapotranspiration) around the central shallow pond enhances the interior air quality and indirectly lightens the interior space. Courtyards were usually designed in rectangular shape and positioned at the centre of the house to function as an interface space between the interior and exterior parts. The high length to width ratio used in their design allows occupants to reside in shaded spaces (towards south) during summer days. Terrace (Eyvan) is a semi-open space, often a three-side closed corridor in front of bedrooms that is typically used to create shady and cool clusters. Terrace (Ravagh) is similar to Eyvan in many ways, but essentially is a semi-open colonnade in the courtyard. As such, Ravagh and Eyvan count as both public and private arenas, suited for family gatherings with the potential to be expanded into each other. These are commonly oriented to the south. South and east oriented ‘Eyvans’ offer very cool and shady places, suitable for summer afternoons. Rooms are located around the courtyard. Hall (Talar) is the largest
room, used for special events and guests. Living room (Talar) is used for gathering of residents and visitors. These can appear in three forms: Haft-Dari (seven doors), Panj-Dari (five doors), or Se-Dari (three doors) rooms. Smaller private rooms are closed from three sides and open from one side (towards open/covered areas). Installation of transparent elements including coloured glasses and porous walls appears to have assisted these spaces in attracting the natural light. Bedrooms are fitted with eastern windows to capture the morning light. Kitchen is usually located near the water wells. Storage spaces with no primary usage are in the eastern side of the courtyard. These spaces mostly receive light through the roof openings rather than opening toward the courtyard. Bathrooms are in the lower level of the houses. A key element that is widely used to reflect and direct the light to the internal layers is water. Pool houses are traditional dwellings containing a central layer around which different functions are formed. These spaces have the capability to receive the light from two sides: the open space or covered area and skylight (ceiling openings). Sufficient headroom for these spaces allow them to receive light from the apertures installed on domes (i.e. ceiling system). The light from above shed on pool and reflects, from water in the pool, to lighten the surroundings.

![Diagram of a typical house plan](image)

**Figure 3. Typical plan – Benchmark house ‘a’: Tabatabaei (Farokhyar, 2013 with modifications)**

The indoor areas can conveniently be divided into three core domains (i.e. quarters), based on lighting levels. The first domain (i) is the nearest indoor space to the openings and receives the daylight directly from the central courtyard. This space has the greatest potential to pass the light to surrounding spaces (i.e. buffer zone i-ii). The second domain (ii) receives the light from the first domain, so too the natural light from wall openings. This space is generally considered as a mediate space for sharing the light. The third domain is effectively a receptor of light from domain ii, as well as small apertures on the ceiling. Figure
4a and 4b illustrate plan and elevation view of study house ‘a’ (Tabatabaei) and the spatial distribution of light through the three interior domains. This is the backbone of the conceptual model to be introduced and discussed in the following section. This data is coupled with the surveyed occupants’ behaviour (particularly movements - from interviews) to plot the occupied interior areas during the course of day and across the three main space domains in Figure 4c (for Tabatabaei House as benchmark). The buffer zone appears to be the only domain which accommodates occupants at all times.

The pool at the heart of house appears to be the main source of indoor light. Given the fact that light, as an isotropic medium, emits from the central courtyard into the interior spaces, daylight’s reach and direction is plotted in Figure 5 for the three historical buildings for cold and warm season. The northern side of buildings appear to attract the least radiated light all year round.

5. Conceptual Model

Urban interior living space is multi-domain and multifunctional: in short, they represent a complex web of independent but interrelated (via lighting) domains. A change made to light pathway, pattern, colour, source or openings orientation is likely to result in impacts on occupants’ lifestyle style in many ways, and it is not always clear what these impacts might be. A simple conceptual model is discussed in two parts: the interrelationship between three core space domains of traditional vernacular style as identified from the archival and field studies combined (Figure 1); and daylight penetrating into each domain that affect
energy efficiency via occupants’ movement (Figure 5). Figure 6 describes how well the indoor directed light within the three core domains affect people, how these enhance or lower as buildings, systems of systems, attempt to become more resilient and sustainable. Although archival studies often suggest a historical tendency towards the deliberate controlled exposure to light in the inner domain (i.e. overlooking central courtyard), observations uncovered the role of managed light in drawing together or separating domains. Where two domains align (e.g. the inner and middle domains), they are most likely to operate effectively to facilitate the space achieve its purpose. Two questions are set here: Can directing the interior light put a control on people (occupant or visitor) autonomy (in entering spaces). Can light work towards or against cohesion between indoor core space domains?

![Figure 5. Radiation of sun from courtyard into the closed space - [a], [d], [g]: Relative position of sun June to December; [b], [e], [h]: patterns of radiation from courtyard in June (warm season); [c], [f], [i]: patterns of radiation from courtyard in December (cold season) – [IRIMO data processed]](image)

The perception of what constitutes the interdependency — and consequent implications — of climatic-responsive vernacular buildings are divers, often conflicting and varying across disciplines. Here, there is ample evidence to suggest that of the interaction between reflected light from central courtyard and indirect lights from wall openings in the
buffer domain i-ii is not managed, the interior space will probably be required to accommodate more physical elements (to achieve the intended cohesion-separation); and this in turn will involve in generation of smaller spaces and consumption of more energy (for ventilation, cooling/heating, and lighting purposes). This is undesirable, given that households are already stretched in terms of resource availability. The view – broadly held and repeatedly appeared in the literature – that occupants/visitors i.e. people organically move between interior spaces over 24 hours and warm/cold seasons is here contended and countered by a tendency of people to reside and remain in the buffer i-ii zone, to benefit from its symbiotic act with the surrounding spaces and the steadier temperature/humidity (Figure 4c, 4d and 6b).

Figure 6. [a] three conceptual domains in a Vernacular form and exchange of light between and across the domains [b] movement towards climatic adaptation and its association with energy conservation for the three conceptual domains (developed by authors)

6. Concluding Discussions

The ‘globalised’ modern architecture, by-and-large, supplies energy (and light) to interior spaces from often unsustainable resources. Consequently, and in absence of natural elements, occupants of modern living spaces have a far lower interaction with their surroundings. With growing population and limited resources, energy conservation has become a grand global challenge. To address that challenge, the common practice is directed toward the use of renewable resources or low consuming systems.

Attached to the tenets of the traditional and hot-and-arid regional architectural forms in Iran, and its symbiotic integration which nature - mainly to exploit and harvest natural energies - is the question of whether the modern architectural forms can benefit from those principles and re-establish the interconnectivity between inhabitant’s behaviour, interior design, and ‘engineered’ natural light. This also begs the question of whether contemporary architectural forms should be centred around occupants, allowing occupants to adapt themselves with daily and seasonal variation of climate. Whilst regional and cultural constraints retain the viability of such an approach a matter for debate, there is no doubt
that the interconnectivity of systems will facilitate the design and development of more sustainable built living spaces.

We took evidence from a wide range of those for whom vernacular buildings provide the focus of their activities (current and former residents, architects, psychologists, city planners, and historians), and distilled the findings into a concise, conceptual model and illustrates our understanding of the light – space – human interaction and also needs of and aspirations for urban living spaces. To illustrate benefits of this enhanced knowledge, a simple conceptual model for present-day urban living spaces is presented. Figure 7 presents the hypothesised conceptual model for a pair of urban flats arranged around an open central courtyard space.

![Figure 7. Central courtyard surrounded with pair of urban flats each containing the three main domains](developed by Authors)

The conceptual model in Figure 7 suites low rise residential buildings, constrained from North and South. Two flats are considered at each level. Flats are suggested to surround a central courtyard. The size of courtyard varies but would be greater than that of typical lightwell patios. The flat on the right side harvests natural light from east, and west, and south. The flat on the left harvest light from north and west and east. Sitting rooms and social interior spaces are accommodated towards the courtyard. This allows a degree of flexibility to the sitting rooms, through encouraging residents to adapt to natural light, daily and seasonally, through adjusting the location of furniture. Benefitting from an enhanced level of awareness, residents indirectly interact with light and adapt themselves with sun radiation variations. Such human response will in turn relax the dependency on the domestic fossil fuel derived energy demands.

7. Conclusions

Human, time, and natural light interact and assessing the implications of that interplay within urban indoor living spaces (in terms of light intrusiveness, spatial coverage and pattern, and extent) plays a vital role in supporting architectural design for enhanced sustainability performance. Contemporary urban buildings do not necessarily cater well for a future of limited resources and energy, raising the cross-cutting question of how interior designers and architects should act to ensure space, environment and people function symbiotically to provide resilience, wellbeing, and sustainable energy consumption.

This work revisited, at some length, the traditional Iranian-Isfahani architectural forms and proposes, on the basis of field observations - in conjunction with historical readings and
interviews - that there exists a link between the daily/seasonal use of spaces and level of
direct and reflected light in interior spaces. The various forms of space usage are controlled
by light conveyance installations (in three levels), and the relative layout and shape of
interior spaces. Installation and interior layouts adopted in this traditional architecture have
had effectively offered a sustainable alternative solution to cooling and lighting demands
through, passively, encouraging inhabitants to adjust their movements and activities, on
hourly and seasonal basis, with ‘engineered’ natural light. It is also proposed that the
benefits of traditional Iranian architecture are fractal, and hence applicable for modern and
often smaller living spaces. We offer conceptual models for the vernacular traditional
buildings and their potential use in the contemporary design. The model tends to
demonstrate how Persian vernacular style accommodated large families and supported
their wellbeing and energy demands. The prospect of using this model as a vehicle to adopt
traditional forms in contemporary urban indoor architecture may beg the question of scale.
To mitigate this, the presence of a buffer domain is discussed that benefits from steady flow
of air, moderated temperature, and lighting levels. The buffer domain naturally
accommodates residents and visitors across seasons and through day time. The peculiar
combination of light generates a natural barrier between that buffer zone and the middle
domains, which can cater the residents and satisfy privacy.

Drawn from the presented model is set of recommendations that we feel are the most
important to put to architectural designers who lead the thinking on bother their occupants
and the energy infrastructure that supports their wellbeing. Advocated recommendations
are:

- working towards architectural designed informed by daylight (position, intensity,
reach and direction) to allow better access to various levels of light and temperature at any
time and at various interior spaces,
- working towards design of flexible spaces that adapt with changing climatic
conditions throughout a year,
- working towards a better symbiosis between occupants’ daily movements, time,
temperature, and levels of illumination,
- putting measures to facilitate the better awareness of occupants of light-space-
time-human interplay and implications in the context of energy conservation.

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Rethinking repetitive housing design typology in hot and humid climate: A case study in Malaysia

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**Abstract:** Repetitive housing in hot and humid climate in Malaysia are designed without much consideration for thermal comfort and adequate natural lighting. Over-heating and lack of natural lighting is a common problem. Due to this, active measure with air-conditioning installation and the use of artificial lighting during daytime is often seen as an instant problem solver. However, due to global warming and depletion of fossil fuels, the dependencies of active system must be reduced. Passive strategies is seen as the best approach in designing better future repetitive houses. Conventional layout and optimized layout using passive strategies is used to compare by performing thermal comfort simulation, daylighting and CFD simulation. Conventional layout uses the current standard practice for design layout and building policy requirements which only requires minimal opening, while optimized layout is based on modification of current standard design layout with improvements to opening requirements in the current building policy. Parameter input used for simulation is based on standard construction materials practiced in Malaysia. Result shows thermal comfort and daylighting improvement between conventional layout and optimized layout. Optimised layout is seen as the future design typology for repetitive houses in Malaysia. However, changes and improvements in the current building policy is essential to implement this.

**Keywords:** Passive strategies, housing, thermal comfort, daylighting

**Introduction**

Climate change has becoming a concern throughout the nations all over the world. The first Climate Change Conference was organized in the year 1995 in Berlin Germany as a kick start to address climate change issues. Recently, 17 Sustainable Development Goals (SDGs) was officially adopted by world leaders on 1\(^{st}\) of January 2016 (United Nations, 2018) targeting to eradicate poverty, fight inequalities and to address the climate change. These ambitious plan and agenda have 5 important segments; people, prosperity, planet, partnership and peace (5P’s) which will be view from the perspective of economic growth, social inclusion and environmental protections (United Nations System Staff College, 2018).

In the year 2016, United Nations (UN) reported that 55% of the world population lives in urban area and it is estimated to increased up to 68% by the year 2050 (United Nations, 2018). The urban population of Malaysia is increasing at 2.1% rate between 2016 to 2030 (United Nations, 2018).

**Malaysia**

Malaysia is a fast develop country located in South East Asia. Surrounded by Straits of Malacca and South China Sea (Central Intelligence Agency, 2018), Malaysia is classified by Köppen-Geiger Climate Classification as Af (equatorial fully humid). A tropical country located near the Equatorial
band with coordinates of N 3°7', E 101° 33' having high humidity between 95% - 100% and minimum temperature of 20.9° and maximum temperature of 35.8° annually (EnergyPlus, 2018). Malaysia also experience southwest monsoon between the month of April to October and northeast monsoons between the month of October to February with monthly rainfall various on locations between 150mm to 550mm (Malaysian Meteorological Department, 2018).

In 1991, Prime Minister, Tun Dr. Mahathir Bin Mohamad announced 9 critical challenges which constitute Vision 2020. One of the significant challenges was gearing up from agricultural base economy to scientific and technology base economy (Mohamad, 1991). As a result, vast jobs opportunities in the industrial sectors in the urban area. Thus, creating housing demand in urban areas. Urban Master Plan and National Housing Policy was also introduced as part of aggressive measures in line with the Vision 2020 (Andrew, 2004).

**Population and urban migration**

Population of Malaysia has reached to 32.0 million in 2017 (Department of Statistic Malaysia, 2018) and is estimated to increase to 41.5 million by year 2040 (Department of Statistics Malaysia, 2016). 69.7% of current population are at the age between 15 to 64 years old. During the year 2015-2016, up to 75% population either migrated from rural to urban area or within states. Among the factors for migrations are career advancement, environment and following the family (Department of Statistics Malaysia, 2017) with Selangor, Pulau Pinang and Johor being the popular destinations. As a result, increasing demands for housing needs (UNESCO, 2018).

![Figure 1: Malaysia urban population (The World Bank, 2018)](image)

**Housing**

Urban population in Malaysia gradually rose from 26.8% to 61.8% between the year 1970 and 2000 (Jaafar J., 2004). However, after Vision 2020 was announced, vast job opportunities and employments, as a result boosting the housing development sectors in urban areas of Malaysia. National Property Information Centre of Malaysia (NAPIC) indicated increase demand of housing in Malaysia. Figure 1 shows total completed housing stock from year 2017 and early 2018. Although there is the light drop during Q1 2018, it is expected to rise later in 2018 (NAPIC, 2018).
Terrace houses being the most popular housing types with 2,248,478 units in 1st quarter of 2018 followed by condominiums and apartments with 838,006 units due to affordability range among Malaysians (Central Bank of Malaysia, 2015). Terrace houses in Malaysia originated from Malacca townhouse during the 17th century and Chinese shophouses in the 19th century. Designed with heavy ornaments on the façade influenced by Dutch and Chinese, the layout includes high ceiling, vent on walls and air well as part of adaptation to local climate which improves the air circulation (S. Vlatseas, 1990).

However, with the influence of modern architecture and availability of electricity, terrace houses have been simplified and ignored the need to adapt to local climate. This is to suit the needs to fulfill the housing demand with maximum profit by developer making it dark and uncomfortable to live in especially during daytime without the intervention of air conditioning units and artificial lighting. Thus, increasing the energy consumptions. Energy Commissions reported that in 1995, total energy consumption was 21,883 ktoe and has increased to 51,806 ktoe in 2015 (Energy Commission, 2017) with residential and commercial being 3rd biggest user with 14.6%. This is expected to rise with the vast usage of air-conditioning units, artificial lighting and refrigerators (Department of Statistic, 2016). Figure 4 shows the percentage of average monthly expenditure for Malaysians with ¼ of it spend on energy.
According to a survey conducted by Kubota, Toe & Ahmad, 62% of terrace home owners owns at between 2 to 3 air-conditioning units which is mainly installed in bedrooms (Kubota T., et al., 2009). This alarming numbers has significantly contributed to the increase of electrical demand in Malaysia. With the current rate usage, the country can only sustain its fossil fuel productions for the next 29 years (Ahmad S., et al., 2011). Moreover, increasing the release of greenhouse gas (GHG) (Hassan, et al., 2014). Hence, it is paramount as an architect, designer and policy makers to address for a more sustainable and environmentally friendly.

Based on figure 5, 6 and 7 urban populations spend more for electricity and cooling equipment in their homes compare to rural populations. This is due to the design of housing in rural areas are more adapted to the local climate. It is also build using local lightweight materials – timber, bamboo and thatch for the roof while the modern houses are constructed with bricks and concrete with less porosity which limits the air movement (Hanafi, 1994). However, the high demand for housing, the used of traditional materials is not attractive as it is expensive and time consuming.
Due to the concern of global warming and climate change, it is important for building professionals to explore on design and means to assist in bringing down the energy consumption on household especially the total dependency of air-conditioning units. Passive design, in general terms, to attain comfort naturally such as building orientation, building layout, size of opening, shading devices and vegetation landscaping.

In 2013, during a Conference for Realizing Sustainability in the Tropics, Tang CK and Chin N in collaborations with Malaysia Department of Works has developed technical passive design guideline for Malaysian building industries. In their guidelines, 8 chapters have been listed in relation to passive design from fundamentals of thermodynamics, heat transfer and thermal comfort, understanding Malaysia weather data, the importance of building form, orientation and core location, daylight harvesting to glazing properties, shading devices, insulation, infiltration and ventilation (Tang C.K. & Chin N., 2013).
Conventional design and layout

Always, a housing development will be designed to accommodate maximum profit for the developer and at the same time fulfill the local authority’ requirements. Planning department guideline for terrace housing blocks, the length should not exceed 97.5m (Jabatan Perancangan Bandar Dan Desa, 2010). Malaysia fire department requires location of fire brigade access and location of fire hydrant to be within 91.5m radius (BOMBA, 2006).

In Malaysia, conventional terrace houses are designed elongated with only 2 frontage having access for natural lighting and ventilation. This is common as it needs to accommodate maximum numbers of houses in a site for maximum return by the developer. Building orientation is often ignored, making some houses facing East and West exposed to high solar gain.

Conventional terrace houses layout has living area, dining area, kitchen and utility room or bedroom and baths on the ground floor and 3 bedrooms and 3 baths on the first floor. For outdoor landscaping, a small patch of green area at the front and yard area. However, this, usually used as an additional car porch space and extension to the kitchen area. Therefore, lack of green area.

According to Mohd Isa M.H., Zhoa X. and Yoshino H. (2010), conventional terrace houses are mostly built using either cement or clay bricks with plastering on both sides and uses cement or clay roof tiles. Very often, if not all the time, these houses do not have insulation material or at bare minimum. Aluminium casement window is usually installed which does not promote continuous natural ventilation without it being open by occupants.

Figure 8: Conventional layout plan and typical design with construction specifications
**Optimised layout**

The optimized layout is designed to be less depth for maximum natural ventilation and lighting into the unit. Larger windows opening is incorporate in all areas. Window type has been changes to louver window to allow for continuous natural ventilation. However, due to the larger exposed façade, sun shading devices is also incorporate above each window. Spaces provision remains the same with additional of family area on the first floor.

*Figure 9: Optimised layout plan*

*Figure 10: Optimised house design with construction specification and installation of louvered window*
Both terrace houses consist of a living and dining area, kitchen, utility, 3 bedrooms and 3 baths. The land area is 92.4m² for conventional layout and 109.5m² for optimized layout. Based on this, passive strategies using new layout and design elements is then incorporated. Daylight and CFD is simulated in Design Builder Software V 4.2.0.054 to compare the difference by adjusting the layout and installation of shading features. Thermal simulation done for 6th of July for 24 hours and based on the highest temperature recorded from weather data for Kuala Lumpur obtain from Energy Plus (EnergyPlus, 2018). Building is South oriented and materials input as per table 1.

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Conventional layout</th>
<th>Optimised layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>150mm think cement brick wall with plastering on both sides</td>
<td></td>
</tr>
<tr>
<td>Internal Wall</td>
<td>150mm think cement brick wall with plastering on both sides</td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>Roof clay tiles with aluminium insulation</td>
<td></td>
</tr>
<tr>
<td>Window</td>
<td>Aluminium frame casement window with 6mm thick single clear glazing</td>
<td>Aluminium frame with 6mm thick glass louvered window</td>
</tr>
<tr>
<td>Shading device</td>
<td>Not provided</td>
<td>Provided</td>
</tr>
</tbody>
</table>

Table 1: Design building parameters used for simulation

**Results**

**Indoor temperature**

<table>
<thead>
<tr>
<th>Facing South</th>
<th>6th July</th>
<th>Original Layout PA Air Temperature (°c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Outside Dry Bulb Temperature (°c)</td>
<td>Conventional Layout Indoor Temperature (°c)</td>
</tr>
<tr>
<td>00:00</td>
<td>26.05</td>
<td>34.47</td>
</tr>
<tr>
<td>01:00</td>
<td>25.45</td>
<td>34.14</td>
</tr>
<tr>
<td>02:00</td>
<td>24.85</td>
<td>33.90</td>
</tr>
<tr>
<td>03:00</td>
<td>24.55</td>
<td>33.73</td>
</tr>
<tr>
<td>04:00</td>
<td>24.28</td>
<td>33.56</td>
</tr>
<tr>
<td>05:00</td>
<td>24.05</td>
<td>33.41</td>
</tr>
<tr>
<td>06:00</td>
<td>24.08</td>
<td>33.27</td>
</tr>
<tr>
<td>07:00</td>
<td>24.10</td>
<td>33.13</td>
</tr>
<tr>
<td>08:00</td>
<td>24.18</td>
<td>33.31</td>
</tr>
<tr>
<td>09:00</td>
<td>25.78</td>
<td>33.39</td>
</tr>
<tr>
<td>10:00</td>
<td>27.80</td>
<td>33.55</td>
</tr>
<tr>
<td>11:00</td>
<td>29.88</td>
<td>33.79</td>
</tr>
<tr>
<td>12:00</td>
<td>31.00</td>
<td>34.05</td>
</tr>
<tr>
<td>13:00</td>
<td>31.80</td>
<td>34.28</td>
</tr>
<tr>
<td>14:00</td>
<td>32.60</td>
<td>34.52</td>
</tr>
<tr>
<td>15:00</td>
<td>33.55</td>
<td>34.77</td>
</tr>
<tr>
<td>16:00</td>
<td>34.55</td>
<td>35.00</td>
</tr>
<tr>
<td>17:00</td>
<td>35.55</td>
<td>35.55</td>
</tr>
<tr>
<td>18:00</td>
<td>34.23</td>
<td>35.76</td>
</tr>
<tr>
<td>19:00</td>
<td>32.13</td>
<td>35.82</td>
</tr>
<tr>
<td>20:00</td>
<td>30.03</td>
<td>35.82</td>
</tr>
<tr>
<td>21:00</td>
<td>28.68</td>
<td>35.78</td>
</tr>
<tr>
<td>22:00</td>
<td>27.50</td>
<td>35.73</td>
</tr>
<tr>
<td>23:00</td>
<td>26.38</td>
<td>35.67</td>
</tr>
</tbody>
</table>

Table 2: Thermal simulation for 6th July from 00:00 hours to 23:00 hours – Temperature Data
Daylighting

The result of daylighting simulation in figure 12 and figure 13 shows improvement from conventional layout to optimise layout. Optimised layout received better daylighting which could potentially reduce the dependencies of artificial lighting. Conventional layout shows that the minimal daylight penetration. This is due to the elongated layout. Artificial lighting will be needed in the centre area of the house. Increasing unnecessary electricity usage during the day.
Figure 13: Daylighting simulation for optimized layout

CFD

CFD simulation results for figure 14 shows air movement are limited compared to figure 15 presents improvement of air flow to all spaces.

Figure 14: CFD result for conventional layout

Figure 15: CFD result for optimized layout
Discussions and conclusion

Simulation result shows improvement to daylighting, air movement and indoor temperature. Potentially to reduce dependencies on mechanical cooling and artificial lighting. However, to stimulate the country to improve on the current terrace housing layout requires drastic change in the current planning regulations, building regulations and building policies.

In Malaysia, initiatives are taken to encourage architects and developers to design and build sustainable and environmentally friendly building. For example, the introduction of Green Building Index and Malaysian Standard – Energy efficiency and use of renewable energy for residential buildings code of practice. However, as these guidelines are not mandatory and does not imposed any penalties. A reform to Uniform Building By-Laws (UBBL) of Malaysia and Planning guideline is required. UBBL 1980, UBBL 1984 (revision 1986, 2003, 2015) item 39 - only indicates that a building to provide minimum of 10% of window opening for natural lighting and ventilation and 5% of opening for uninterrupted passage of air. New UBBL and Planning guideline must include a more robust sustainable building requirement.

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Chapter Four: Sustainable construction technologies, Resource efficiency & Renewable energy and green technologies
Compressive Strength of Interlocking Compressed Soil Blocks (ICSB) Produced Using Soil and Production Water from Oil Fields in Oman

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Abstract: Large quantities of water are used in the oil fields in the oil production process. Naturally, such water is always contaminated with oil compounds. Although production companies such as Petroleum Development of Oman (PDO) treat the water to many stages of refinement, yet a large quantity of it remains hazardous to man-use. Methods of treating production water are generally very expensive and similarly are the methods of their disposal. Normally, small quantity of treated water is recycled in the production process, but a large proportion has to be disposed-off. PDO uses deep injection at depths in excess of four kilometres inside the earth in order to avoid contamination of underground aquifers, an extremely expensive process. The research objective of the current research is twofold: to use the treated production water and thus help solving an expensive problem created by the oil production, and to provide a cheap alternative to the widely used concrete blocks in construction industry. For this purpose, soil and water were obtained from Marmoul and Nimir oil fields in Oman. Soil tests were performed to check the suitability of the soils for the production of Interlocking Compressed Soil Blocks ICSB and to select a suitable type of stabilizer to be used. Tests have shown that soil from both sites were suitable for the production of blocks. Both soils contained a small percentage of clay, and accordingly, cement was used as a stabilizer for making the compressed blocks. To determine the strength characteristics of the produced blocks a program of testing was designed to include mixes of different proportions of soil, cement and water. Results indicated that it is possible to use production water for the manufacture of ICSB with good strength suitable for both load-bearing and non-loadbearing applications.

Keywords: soil, blocks, strength, oil, PDO

Introduction

One of the roles of the sustainable development strategies in the developing countries is to provide decent welfare to the community through providing the basic needs to its people such as clean and potable water, housing, clean environment, etc. at affordable and cheap means. In many developing countries, it is necessary to seek ways to reduce construction costs, especially for low-income housing, as well as adopting easy and effective solutions for their repair and maintenance (Adam and Agib, 2001). This objective can be partially achieved through the use of locally available materials in the construction of low-income housing. Soil is available in abundant quantities all over the world. Its use in the construction industry is significant in uses such as cement mortars, concrete, finishing, cement blocks, and soil compressed blocks and bricks. Soil compressed block system is one of the traditional construction materials that exists in many developing countries which have proved to be suitable for a wide range of buildings and which have a great potential in the construction of traditional low-cost dwellings. Adam and Agib (2001) reported that soil construction methods are used in 80% of urban buildings and exceeds 90% in rural areas in Sudan. Often a stabilizer material such as cement or lime is added in small quantities in order to improve the mechanical properties and durability of the blocks.

While a tremendous work has been done on properties of ICSB produced using indigenous soils in different parts of the world, to the knowledge of the authors, no work
has been published on ICSB made using production water from oil fields, except those by the authors (Al-Jabri et al., 2016, and Al-Jabri et al. 2017). This paper describes the work done to characterize the interlocking compressed soil blocks made using production water from oil fields.

Materials Used

Soil

Soil used for the manufacture of the compressed soil blocks was provided by PDO from two oil production fields in Oman: Marmoul oil field and Nimir oil field. It is not mandatory that soil has always to be from oil fields, but since water was supplied from there, the proposed solution can use the available at the site. The use of local soil will reduce the cost of transportation and affects also the cost of production of the produced blocks. To determine suitability of the soil for block production, laboratory tests were performed on the two types of soils. These tests included determination of specific gravity, plasticity index, clay content and particle size distribution.

Water

Water used for the manufacturing of the compressed soil blocks was the oil production water which was also supplied by PDO from Marmoul and Nimir oil fields. The supplied water is secondary-treated by PDO. Chemical analyses have been carried out on the water samples from these sites to determine their content of heavy metals, solids and organics.

Results of Soil Tests

Specific Gravity Test

Specific gravity test for the two soils was carried out in accordance with ASTM D854 (2002). Two soil samples for each site were selected for testing. The results showed that the two soils have almost the same specific gravity of 2.69 in average.

Atterberg Limits

Tests on soil samples from the two sites were done in accordance with ASTM 4318 (2000). The test results showed that Marmoul soil has liquid limit (LL) =29%, plastic limit (PL) =18%, and plasticity index (PI) =11%, whereas these values were zero for Nimir soil. The results also showed that Nimir soil contains more sand/silt and had no plasticity. For Marmoul soil these values for LL, PL and PI fall within the limits specified by ARS 680 (1996) for production of compressed blocks. However, since Nimir soil has no plasticity, its suitability has to be assessed by other tests.

Sieve Analysis Test

Sieve analysis test was carried out to determine the particle size distribution (grading) of the soil, in accordance with ASTM 422 (1998). To produce a soil-cement block with good properties, it has been suggested that the soil should contain about 15% gravel, 50% soil, 15% silt, and 20% clay at the most (Juma, 2015). Since the soil contains fine particles i.e. silt and clay, three analyses tests were conducted: sieve analysis test, wet sieve analysis test, and hydrometer test for soil particles passing 75µm.

The results from these tests for Marmoul and Nimir soils are shown in Figure 1. Figure 1 shows the particle distribution curves for the two soils plotted together with the
limits set by ARS 680 (1996) for soils suitable for block production. It is clear from the figure, the two soils have almost the same distribution, both are within limits specified by the ARS 680 (1996) for compressed earth blocks but Nimir soil falls better within these limits.

![Figure 1: Particle Size Distribution for Nimir and Marmoul Soils compared with ARS 680(1996) limits.](image)

The results also show that, while the quantities of clay in the two soils are almost the same (2.25% for Marmoul and 2.02% for Nimir), Nimir soil contains more silt than Marmoul soil (18% compared to 11%). The quantity of clay in the soil controls the selection and the amount of the stabilizer to be used. For soils with high clay content, only lime can be used to stabilize the soil. With the low clay content as in Marmoul and Nimir soils, cement can be used as a stabilizer prior to compressing the soil. However, the quantity of the cement stabilizer can be determined by testing a number of mixes with various stabilizer proportions. Soils with higher clay contents compress more than those with lower clay content. In the present case, it is expected that Marmoul soil will require more volume of soil to make the same block than of Nimir soil, due to its higher compressibility.

**Results of Water Tests**

Chemical analyses were carried out on the water samples from Nimir and Marmoul sites to determine their content of heavy metals, solids and organics. Measurements also included certain impurities that could affect the properties of the soil-cement blocks such as total alkalinity, sulfate content, chloride content, total dissolved solids and water hardness. Other parameters such as pH and conductivity were also measured. Results are shown in Table 1.

Results indicate that the salinity (electrical conductivity) of the produced water samples from Nimir is higher than the ones from Marmoul. This is evident from the higher Total Dissolved Solids (TDS) values (8300 mg/L in Nimir water samples compared to 4780 mg/L in Marmoul water samples). Moreover, the chloride content in Nimir water samples (4378 mg/L as Cl⁻) is higher compared to Marmoul water samples (2136 mg/L as Cl⁻). The sulphate (as SO₄) and hardness (as CaCO₃) contents in Nimir water sample (333 mg/L and 350 mg/L) are higher compared to Marmoul water sample (120 mg/L and 140 mg/L). However, total alkalinity (as Na₂O) in Nimir water samples (190 mg/L) is lower compared to Marmoul water samples (472 mg/L). The content of heavy metals is relatively low in the water samples from both sites (most are below detection limit except Boron which was in
the range of 4 mg/L). Moreover, oil and grease content was found below detection limits in the water samples from both sites (i.e. less than 5 mg/L).

Table 1. Water quality specifications for producing concrete (adopted from Chini et al. (1999)

<table>
<thead>
<tr>
<th>Chemical Limit mg/L</th>
<th>Specification</th>
<th>NIMIR Water</th>
<th>Marmoul Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphate as SO₄⁻</td>
<td>3000</td>
<td>3000</td>
<td>333</td>
</tr>
<tr>
<td>Total Chloride as Cl⁻</td>
<td>500</td>
<td>1000</td>
<td>4378</td>
</tr>
<tr>
<td>Total solids</td>
<td>50000</td>
<td>50000</td>
<td>8300</td>
</tr>
<tr>
<td>Alkalis as Na₂O eqv.</td>
<td>600</td>
<td>600</td>
<td>190</td>
</tr>
</tbody>
</table>

Water quality specifications for producing concrete mixes according ASTM C94 (2000) and AASHTO M157 (2017) are shown in Table 1. It can be seen that both water samples from Nimir and Marmoul meet the limits of total solids (<50000 mg/L), sulphate (<3000 mg/L) and alkalinity (<600 mg/L). However, the chloride content is higher than the specified maximum limits (>500 mg/L).

**Trial Mixes to Assess Compressive Strength of blocks**

Fifteen Mixes of soil, cement and water were prepared in the laboratory as shown in Tables 2 and 3. The parameters of the study included the following:

1. **Water Content**: Using Soil/Cement=8.0, and Water/cement =1.75, 1.5, 1.25, 1.0
2. **Cement Content**: Using Water/cement=1.5 and Soil/Cement= 4, 6, 8, 10
3. **Curing Regimes**: Using Soil/Cement=8.0 & Water/cement=1.5, four different regimes were considered and are listed in Table 4.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mix</th>
<th>Cement</th>
<th>Soil</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content</td>
<td>MAR01</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>MAR02</td>
<td>1</td>
<td>8</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>MAR03</td>
<td>1</td>
<td>8</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>MAR04</td>
<td>1</td>
<td>6</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>MAR05</td>
<td>1</td>
<td>4</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>MAR06</td>
<td>1</td>
<td>10</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>MAR01</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>NIM01</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>NIM02</td>
<td>1</td>
<td>8</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>NIM03</td>
<td>1</td>
<td>8</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>NIM13</td>
<td>1</td>
<td>8</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td>NIM04</td>
<td>1</td>
<td>6</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>NIM05</td>
<td>1</td>
<td>4</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>NIM06</td>
<td>1</td>
<td>10</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>NIM01</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
</tr>
</tbody>
</table>

*MAR: Marmoul soil and water, Nim: Nimir soil and water
Table 3. Mixes to study effect of curing regimes

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cement</th>
<th>Soil</th>
<th>Water</th>
<th>Curing Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIM07</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
<td>1</td>
</tr>
<tr>
<td>NIM08</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
<td>2</td>
</tr>
<tr>
<td>NIM09</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
<td>3</td>
</tr>
<tr>
<td>NIM01</td>
<td>1</td>
<td>8</td>
<td>1.50</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 4. Curing regimes used in the study

<table>
<thead>
<tr>
<th>Designation</th>
<th>Condition of curing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regime 1</td>
<td>All days under shade inside Lab + Spray + No Coverings</td>
</tr>
<tr>
<td>Regime 2</td>
<td>All days under shade outside Lab + Spray + No Coverings</td>
</tr>
<tr>
<td>Regime 3</td>
<td>All days under shade outside Lab + Spray + Plastic Coverings</td>
</tr>
<tr>
<td>Regime 4</td>
<td>All days under shade outside Lab + No Spray + Plastic Coverings</td>
</tr>
</tbody>
</table>

Production of blocks

The soil was first sieved through 10mm wire mesh. Larger lumps retained on the sieve were tamped with a plastic hammer and re-sieved. A standard measure was used to batch the soil, water and cement (Rigasse, 1985). The dry materials were thoroughly mixed in a cylindrical mixer, then water was added. The mixture was allowed to mix in the mixer for few minutes, then removed from the mixer and batched using standard buckets of 10 litres size. The semi-wet mix was placed in three layers in the box of the CINVA RAM machine, Figure 2, each layer was pressed with the fingers on the sides and the corners before laying the next layer. After the box of the machine was full with the soil mixture, the lid of the box was placed to cover the soil mix and the machine handle was pulled down to compress the soil. After a full swing of the handle, the box was opened and the block was ejected from the machine. The block was then removed on plastic pallets and placed on steel rails to dry in the open air of the laboratory. After 24 hours in the open air in the laboratory, the blocks were removed to the curing area under one of the curing regimes in Table 4, and were left there until the date of testing.

The CINA RAM press used here was imported from the Asian Institute of Technology (AIT), Thailand. The machine can produce blocks in four shapes (Figure 3): a standard rectangular block with size 300x150x100 mm, with two circular holes, each with diameter 50 mm, a central rectangular hole 45x25 mm and two rectangular holes 25x25mm one at each edge. Using a single vertical insert the machine can produce half size rectangular block 150x150x100 mm with a single hole in the middle of its face. Furthermore, with another special insert, it can produce channel blocks 300x150x100 mm with a slit running the full
length of the block. Half size channels 150x150x100 mm can also be produced using the half size insert.

![Figure 2. Modified CINA RAM press](image)

Rectangular

Half Rectangular

Channel

Half Channel

![Figure 3. Different shapes and sizes produced by the Modified CINVA RAM press](image)

To monitor the development of strength in each mix, blocks were subjected to a compression test after curing for 7 days and 28 days of casting. A minimum of five blocks were used for testing at each age. The blocks after being taken out of the curing area were weighed, given an identification number, and were placed in the Dartec compression machine. Special platens made specially to suit the grooves and the protrusions on the bottom and top surfaces of the block were provided by the manufacturer. Load was applied gradually at a loading rate of 2 kN/s until the failure of the block, when the ultimate load was recorded. The strength of the block was calculated by dividing the ultimate load by the gross area of the block (ASTM 67, 2003, and OSI, 1977).

**Discussion of Results**

The effect of water/cement ratio on the compressive strength of the block is shown in Figure 4. The figure shows the variation of the block compressive strength at 7 days and at 28 days of curing for blocks from Marmoul and Nimir soils. The variation of strength of the block with the water/cement ratio is very significant for both soils. Block strength increases with an increase in water cement ratio up to an optimum, then drops after that. For both soils, the compressive strength of the blocks drops outside the water cement ratio range of...
1.25 to 1.75. This suggests that the optimum values for both soils are between 1.3 and 1.5 water/cement ratio.

Figure 4. Effect of water content on the compressive strength of blocks (Soil/Cement=8)

It can also be observed that the block compressive strength for all mixes increases with age for all values of water /cement ratios, which shows the effect of the stabilizer in developing the strength of the block with age as more particles are hydrated. At a water cement ratio of 1.5, for example, the 28-day strength is 1.9 times the strength at 7 days for Nimir blocks, while for Marmoul blocks the ratio between the strengths at the two ages is 1.75.

The effect of soil/cement ratio on the compressive strength of the blocks is shown in Figure 5. The figure also shows the variation of the block compressive strength at 7 days and at 28 days of curing. The effect of soil/cement ratio on the compressive strength of the block is significant for both types of soils. In general, the block compressive strength decreases with the increase in the soil/cement ratio, with almost the same pattern for both soils. A drop in the 28-days compressive strength of 80% can be observed when the soil/cement ratio is increased from 4 to 10 in both Nimir and Marmoul blocks. Using a specified block compressive strength, the required soil/cement ratio can be obtained from this graph. For example, the Omani Standard, OS1 (1977) specifies a 28-days compressive strength of 3.5 MPa for concrete blocks to be used in non-load bearing applications. If the same limit is applied to the soil blocks in this study, Figure 5 suggests a value of soil/cement ratio of 10 for both soils.

The effect of curing the blocks under different curing regimes on the strength of the blocks is shown in Figure 6. Blocks from Nimir soil were used to study this effect, having mix proportions of cement: soil: water of 1:8:1.5. The blocks used had the same mix proportions and were cured under different curing regimes as described in Table 3 before. Regimes 3 and 4 had the greatest effect on the block compressive strength. In both regimes, the blocks were covered with polythene covers and were kept under shade outside the laboratory. Regime 3 is similar to Regime 4 in the overall conditions, but in Regime 3, the blocks were sprayed with water daily and then covered. The results presented in Figure 6 indicate that water spraying does not produce significant improvement in strength with these regimes of curing (maximum of 7% increase). Noting the difficulty of using water spraying with these regimes and the increase in quantity of water used which produces only
marginal gain in compressive strength; it is recommended to use Regime 4 with no water spraying for curing.

![Figure 5. Effect of the soil/cement ratio on the compressive strength of the blocks (water/Cement=1.5)](image)

![Figure 6. Effect of curing regime on compressive strength of the blocks](image)

**Conclusions**

In this study, soil and water for manufacturing compressed soil blocks were obtained from Marmoul and Nimir oil fields. Tests were done to characterize the soil for checking its suitability for making compressed soil blocks. Soil-cement blocks were manufactured using a manual Cinva-Ram press. Effects of water content, cement content and curing regime were studied. From the study, it can be concluded that production water can be used to manufacture interlocking compressed soil blocks (ICSB) with good compressive strength by adjusting the controlling parameters of water/cement ratio, soil/cement ratio and curing conditions. For Marmoul soil, water/cement ratio of 1.5 gave optimum compressive strength at 28 days, while for Nimir soil, optimum result at 28 days was obtained with water/cement ratio of 1.3. At 28 days, the Omani standard OS1 for concrete blocks requires a minimum strength of 3.5 MPa for non-load bearing blocks. Accordingly, Marmoul soil can be used to make compressed soil cement blocks with a soil/cement ratio of about 9.5.
Nimir soil can be used to make compressed soil cement blocks for non-loading bearing with a soil/cement ratio of about 10. At 28 days the Omani standard OS1 for concrete blocks requires a minimum strength of 7 MPa for load bearing blocks. According to the standard, Marmoul soil can be used to produce load bearing soil cement blocks using a soil/cement ratio of about 5.5 whereas Nimir soil can used to make loading bearing compressed blocks with a soil/cement ratio of about 6. The best curing regime was found to be Regime 4, in which the blocks must be shaded, covered with polythene covers and requiring little or no water spraying.

Acknowledgements

The project’s investigators would like to express their gratitude to Petroleum Development Oman (PDO) for providing financial support to the project under the grant number: CR/ENG/CIVL/14/09. Also, our sincere gratitude is extended to the Asian Institute of Technology (AIT) for the scientific cooperation in this work.

References


Biological modeling as a tool for promoting sustainable construction technologies and improving the energy efficiency

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Abstract: It is generally known that nature is considered to be a unique and optimal encyclopedia for various sorts of technological ideas. A new approach of rethinking in nature can easily be contributed by bio-mimicking an organism’s form and construction to the building. There is strong evidence that imitating natures’ mechanisms, inventions and implementing natural innovation based on a scientific basis can significantly improve the quality of technological aspects and result in sustainable multi-functional structures and superior technologies. A gap in knowledge was found regarding the sustainable bio-mimicked construction system of a building and its impact on the energy efficiency. The paper presents a theoretical basis, and cases study analytical strategies. The Bio-mimetic levels and approaches in Architectural technology and its advantages when applying in the light of building sustainability and energy efficiency are defined. The Bio-mimicry in construction technologies and its relation to the energy efficiency of the building are also discussed. The Sino Steel International Plaza in China and the Swiss Re headquarters in London are analyzed as case studies discussing their sustainable bio-mimicked construction technologies and its effect on the energy efficiency of the buildings. Summarily, our results provide evidence that there is a strong positive relationship between the sustainable construction technologies and the energy efficiency of a building and applying the sustainable bio-mimetic approach in construction technologies may lead to financial savings and a better level of energy efficiency in the building as well.

Keywords: Bio-mimicry, organism’s form, sustainable construction, sustainable technology, energy efficiency

Introduction

Throughout the history of Architecture, some sorts of inspiration have been adapted by natural forms and processes. Nowadays, it seems that not only the Bio-morphed Architecture has been a renewed interest, but also, the improvement in construction Technologies as a result of the Bio-mimetic approaches in thinking and designing, has strongly been leading to Biological modeling, in order to learn from a natural source of ideas which has benefited from billions of years in the field of research and development. Biological modeling may consider being a co-evolutionary scheme in learning from the extensive array of natural species.

Natural creatures made forms as an integral part of their structures such as bones, and nails. They also made them separately such as the spider web, and cocoon shells. These natural structures have been created as multi-functional and amazingly tough structures. As was mentioned by Bar Cohen, there are various sorts of structures that represent magnificent engineering skills such as the honey-comb shape. The cellular hexagonal structure of the honeycomb has been made with the least amount of materials. Moreover, it is considered to be a filler structure and provides an impressive and efficient space with high compressive strength.
and low weight. It is also been used as a noise insulation design solution interiorly in the buildings (Bar Cohen, 2012).

In fact, the approaches of bio-mimicry as a designing process can be easily divided into 2 parts: the first part is to determine the human need or the designing problem, the second part is looking in nature for expectable solutions such as a specific characteristic or a particular behavior or a way of adaptation of an organism and translate that to a designing buildable theme as a first influencing step to the essential solution (Maglic, 2014). The previous approaches require the cooperation of designers and biologists for guaranteeing the perfect match of the biological solution to the designing problem (Maglic, 2014).

The term ‘biomimicry’ first appeared in 1962 and developed among scientists in the 1980s (Pawlyn, 2011). Julian Vincent defines it as ‘the abstraction of good design from nature’ (Vincent, 2014), while for Janine Benyus it is a new discipline that studies nature's best ideas and then imitates these designs and processes to solve human problems. Studying a leaf to invent a better solar cell is an example. It is an "innovation inspired by nature" (Singh and Nayyar, 2015).

Research Objectives

This is an account of a descriptive study of the effect of biological modeling on promoting the sustainable construction technologies, and improving the energy efficiency as well. This research aims to shed the light on the sustainable bio-mimicked construction system of a building and its impact on the energy efficiency through the biological modeling of an organism in order to improve the energy efficiency, and optimize the financial savings as well.

Research Methodology

The research presents a theoretical basis, and case studies analytical strategies. The Sino Steel International Plaza in China and the Swiss Re headquarters in London are analyzed as case studies discussing their sustainable bio-mimicked construction technologies and its effect on the energy efficiency of the buildings.

Literature Review

Levels of Bio-mimicry

There are three levels of Bio-mimicry; the organism, behavior, and ecosystem. The first level is the organism level which can be described as the imitation of a certain organism such as animals or plants, the organism can be partially or totally imitated. The second level is the behavior level which can be described as the imitation of the behavior of an organism or the way it adapts to a larger context. The third level is the Eco-system level which can be described as the imitation of an entire eco-system with its eco-principles that permit the ecosystem to be functioned in a successful way (Fish and Benesk, 2014).

In this quest, we can easily say that under each level of Bio-mimicking nature, there are five sub-levels of imitating as shown in Figure 1. The first sublevel is the form (what it looks like), the second sublevel is the material (what it is made from), the third sublevel is the
construction (how it is made), the fourth sublevel is the process (the steps in which it works), and the fifth sublevel is the function (what it can do) (El Ahmar, 2011).

![Levels of Bio-mimicry](image-url)

**Figure 1** The Levels of Bio-mimicry. (Source: Authors).

*Bio-mimicry (The Organism level)*

There are various extensive examples that humans experienced; in the field of energy and materials, through natural organisms that have already directed to them in effective ways.

An example of that is the Namibian desert beetle (the stenocara). This beetle lives in the desert with a very few amounts of rainfall yearly. It has the ability to catch moisture from the moving fog over the desert through angling its body in the wind. The droplets were formed on its rough surface and flowed down into its mouth (Garrod et al, 2007).

Matthew Parkes of KSS Architects explained their way of thinking through bio-mimicry at the organism level while designing the Hydrological center for the University of Namibia. Parkes bio-mimicked the Namibian beetle at the organism level as shown in Figure 2 to produce a sort of a Fog catcher design for his project (Maglic, 2014).

![Figure 2](image-url)

**Figure 2** Matthew Parkes’ Hydrological Center for the University of Namibia and the stenocara beetle. (Adapted from: Zari, 2007).
Bio-mimicry in Construction Technologies

Janine Benyus, the founder of the bio-mimicry institute mentioned that buildings which follow the Bio-mimetic inspirations can easily reach sustainability because bio-mimicry is related to the Life’s principles. The buildings applied these translations can perform well as natural strategies are always effective. They can also save energy, and minimize material costs by mimicking the natural shapes; it would be more economical to concentrate the building’s design shape rather than its materials. They can redefine Waste because natural and biological analogs are optimally and automatically manage unnecessary redundancies (Benyus, 2002).

However, there are several examples of applying the bio-mimetic approaches in the field of architectural technology such as the fiberglass technology in crocodile skin; this natural property has been existed in crocodiles since day one of their creation. Researchers found out that the collagen protein fibers in the crocodile skin have its own special strength to the extent that it is unaffected by arrows or even bullets (Yehia and Mossman, 2006). Fiberglass is a composite material that made from natural silica mixed with other materials with a very high tensile strength. Fiberglass technology has been lately used in architecture through various applied materials and systems such as the fiberglass windows systems in any building façade (Peter Arsenault, 2010).

This can strongly relate to the constant self-cleaning technology that was bio-mimicked from the lotus plant. Although the lotus plant grows in a very dirty and muddy environment, surprisingly its leaves are always clean. The lotus plant waves its leaves for pushing the small particles of dust to a certain spot where the raindrops are always felled to wash away the dirt. In this quest, a German company called ISPO had produced and well modified a house paint called ‘Lotusan’ that enjoy the same characteristics of the lotus plant. This product can also guarantee its self-cleaning properties for almost five years (Robbins, 2011).

Significantly we must mention that the conversion of the construction industry into a sustainable paradigm is critically important for the local economic growth. This conversion is also vitally essential for minimizing the energy, natural resources consumption, and waste production. The first step to this conversion is the development of indicators through the participation of stakeholders and effective government (Oguntona and Aigbavboa, 2017). As Kibert mentioned, it may have to be a particular change in the construction stakeholders’ mindset with technology, policy, and education as noticeable sectors in the process of this conversion (Kibert, 2016).

Adopting sustainable technologies and materials in the construction industry can reduce its impact on the environment (Oguntona and Aigbavboa, 2016). Several bio-mimetic technologies and innovations are already commercialized and copyrighted in which they offer their potential in promoting sustainable specifications in the industry of construction. Some examples of bio-mimicked sustainable construction technologies have been explained in the following table.
Table 1 Examples of bio-mimicked sustainable construction technologies. (Source: The Authors)

<table>
<thead>
<tr>
<th>Steel cable Technology in Muscles:</th>
<th>The load-bearing cables in suspension bridges are composed of bundles of strands, just like our muscles.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tendons are one of the giant examples of God’s creation and natural composites. They have consisted of tissues that connect the muscles to the bones. They are made from collagen-based fibers (Benyus, 2002). In fact, the steel cable technology that was used in the construction of suspension bridges was been inspired and biomimicked the tendons’ structures of the human body as shown in Figure 3.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3 The mimicking of Muscles Tendon’s Concept in Load Bearing Cables. (Adapted from: Yehia, and Mossman, 2006).

<table>
<thead>
<tr>
<th>The Radiolarian design as a model for the dome structure:</th>
<th>Figure 4 The mimicking of Radiolarians in a Dome structure. (Adapted from: (online), Scadesign.com, accessed on 2 May 2018).</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Radiolarians are living organisms that live in the sea which are considered to be vital catalogs of optimal design problematic solutions. The S. Pavilion at Expo 76 in Montreal is one of the large-scale projects that bio-mimicked the radiolarians in the design of the Pavilion dome as shown in Figure 4.</td>
<td></td>
</tr>
</tbody>
</table>

A Comparative Analysis between the Sino Steel International Plaza in Tianjin, China, and the Swiss RE Headquarters (Gherkin Tower) in London, England

The Projects’ Basic Information

The basic information of each project was mentioned briefly in the following table.

Table 2 The Basic information of the Sino Steel international plaza in China and the Swiss RE Headquarters (Gherkin Tower) in England. (Adapted from: (online), archdaily.com, accessed on 7 May 2018).

<table>
<thead>
<tr>
<th>Points of Comparison</th>
<th>The Sino Steel International Plaza in China</th>
<th>The Swiss RE Headquarters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Points of Comparison</td>
<td>The Sino Steel International Plaza in China</td>
<td>The Swiss RE Headquarters (Gherkin Tower) in England</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>Project Description</td>
<td>The Sino Steel building is a 358-meter height, the upper levels are a luxury hotel, it also consists of 3 levels of high luxury residential flats, a giant restaurant and a VIP Spa for the hotel guests. There is a podium also that connects both of the 2 towers which serve as a public space for the hotel guests; it contains reception areas, western restaurant, Japanese restaurant, Chinese restaurant, lobby and ultra lounges, conference center and several retail shops (Archinet official website).</td>
<td>Swiss Re Headquarters is considered to be a landmark building in the financial center of London. The Swiss RE is a 40 levels office building; there are some retail spaces that are opening onto a landscaping area. At the upper levels, the events facilities and dining areas are also been located (Archinet official website).</td>
</tr>
<tr>
<td>Idea of Architect</td>
<td>The decision of the architect here is to design a honeycomb façade; the skin is the structure of the building. There is no internal structure which frees up the plan of the building for much flexible use.</td>
<td>The decision of the architect is to design an environmental landmark that enjoys an economical form and deeper vision of the urban context.</td>
</tr>
<tr>
<td>Challenge to be</td>
<td>The design of the architect</td>
<td>The design of the architect intends</td>
</tr>
</tbody>
</table>
achieved challenges the prevalent construction technology for creating an optimal mixture of beauty and strength. to create an architectural, technical, and social landmark building.

The Projects’ Bio-mimetic Comparative Analysis

A comparative analysis has been created to show the bio-mimetic approaches used in both of the projects in the following table.

Table 4 A Bio-mimetic comparative analysis between the Sino Steel international plaza in China and the Swiss RE Headquarters (Gherkin Tower) in England. (Source: Authors)

<table>
<thead>
<tr>
<th>Points of Comparison</th>
<th>The Sino Steel International Plaza in China</th>
<th>The Swiss RE Headquarters (Gherkin Tower) in England</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bio-mimetic Approach used</strong></td>
<td>The Honey-comb Shape is bio-mimicked by the Sino Steel building.</td>
<td>A micro-organism called “The Glass Sponge” is bio-mimicked by the Gherkin tower.</td>
</tr>
<tr>
<td><strong>Bio-mimetic Main Level</strong></td>
<td>Organism Level</td>
<td>Organism Level</td>
</tr>
<tr>
<td><strong>Bio-mimetic sublevel</strong></td>
<td>Form Mimicked</td>
<td>Form Mimicked</td>
</tr>
<tr>
<td></td>
<td>Material Un-mimicked</td>
<td>Material Un-mimicked</td>
</tr>
<tr>
<td></td>
<td>Construction Mimicked</td>
<td>Construction Mimicked</td>
</tr>
<tr>
<td></td>
<td>Process Un-mimicked</td>
<td>Process Un-mimicked</td>
</tr>
<tr>
<td></td>
<td>Function Un-mimicked</td>
<td>Function Un-mimicked</td>
</tr>
</tbody>
</table>

The Projects’ Bio-mimetic Detailed Analysis

First: The Sino Steel International Plaza in China.

The following discussion represents a detailed comparative analysis of the Sino steel project and the bio-mimetic approach used for it.

Table 5 Bio-mimicking the form of the honeycomb cells in the design of the Sino Steel building. (Source: Authors)

<table>
<thead>
<tr>
<th>Bio-mimicked Form (The honey-comb cells multiplying)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The shape of the honeycomb is a hexagonal cellular shape structure that the honey bees utilize for their safe containment. This structure is naturally been created by the least amount of materials and offered a highly efficient container for food storage packing in their off springs (Bar Cohen, 2016).</td>
</tr>
<tr>
<td>The building design has consisted of a perfect mixture of shape and structure; an optimal repeated motif of hexagonal multiplying cells façade with the gross height of the building. The façade is done up of 5 various sizes of hexagonal windows. This irregular pattern of windows’ sizes across the façade creates an ever-transforming image of the building from several perspectives.</td>
</tr>
</tbody>
</table>
The honeycomb hexagonal units.
(Adapted from: (online), featurepics.com, accessed on 2 May 2018)

Figure 6 The Sino-steel plaza hexagonal units’ façade. (Adapted from: (online), worldofarchi.com, accessed on 2 May 2018).

Table 6 Bio-mimicking the construction of the honey-comb cells’ structures in the design of the Sino Steel building.
(Source: Authors)

<table>
<thead>
<tr>
<th>Bio-mimicked Construction (The Honey-comb cells’ structures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The honeycomb structure can naturally guarantee the minimization of the material used in order to reach the minimum material cost and the minimum weight. The common feature of this structure is limited in the form of hollow cells array located between narrow vertical walls. The honeycomb is a hexagonal shaped structure which offers a minimum density material and high compression, and shear properties (Bar Cohen, 2016).</td>
</tr>
<tr>
<td>The honeycomb façade (the building’s skin) is the structure. There are no internal structures for much flexible use. This natural design solution challenges the conventional construction schemes for presenting an optimal combination of strength and beauty.</td>
</tr>
</tbody>
</table>

Figure 7 The Sino Steel International Plaza Façade shapes. (Adapted from: (online), worldofarchi.com, accessed on 2 May 2018).

Figure 8 The Honey-comb shape building up the structure for the Sino-Steel plaza. (Adapted from: (online), worldofarchi.com, accessed on 2 May 2018).
Second: The Swiss RE Headquarters (Gherkin Tower) in England

The following discussion represents a detailed comparative analysis between the Swiss RE project and the bio-mimetic approach used for it.

Table 7 Bio-mimicking the form of the glass sponge skeleton in the design of the Gherkin Tower. (Source: Authors)

<table>
<thead>
<tr>
<th>Bio-mimicked Form (the Glass sponge skeleton shape)</th>
</tr>
</thead>
</table>

The Glass sponges are living organisms that live in the deep ocean. Their tissues have naturally consisted of glass structural particles made of silica. The Tiny siliceous parts of the glass sponge’s skeleton are called ‘spicules’. The glass sponge’s biological design offers a large number of spicules that connected together to form a beautiful pattern which called glass house. We can easily say that the glass sponge skeleton consists of a network of spicules that connected together to form a matrix that determines the outer shape of the sponge skeleton (Jeon, 2013).

- The tower’s external skeleton can be described as a diagonal braced pattern with a retail public space on the ground floor in a double arcade. Large triangular archways at the entrances of the building cut out the façade’s diamond grid.
- There is a spiral atrium at the end of each floor produced by the twisting design of the building’s plan. This permits the easy flow of natural ventilation due to the difference of the large pressure that pushes the air into the horizontal slots of the cladding.
- The building’s envelope at the height of office spaces consists of an outer layer and an inner skin. The outer layer is a double glazed layer while the inner skin is a single glazed one. The cavities between the outer and inner layers contained solar control blinds. These cavities serve as buffer zones to minimize the mechanical heating and cooling.

Figure 9 The glass sponge’s diamond-shaped context. (Adapted from: (online), researchgate.net, accessed on 7 May 2018)

Figure 10 The Architect Sketch for designing the triangular façade. (Adapted from: (online), architectural.com, accessed on 7 May 2018)
The main skeleton of the glass sponge consists of a network of a large number of spicules that connects together to form a matrix that determines the body shape of the sponge skeleton. The secret behind the structure of the glass sponge lies at the repeated module of a diagonal triangular complex matrix that can act as a whole entire structural system (Jeon, 2013).
Results & Conclusion

The results achieved for the Sino Steel building in China through bio-mimicking the honeycomb in Organism level were as the in the following:

**In terms of Energy Efficiency & Heat gain and Loss**

In fact, the randomly outer pattern of the building envelope strongly responded to the patterns of Sun, and Wind (Montuori et al, 2015). Through the optimal directing of solar direction, and various air flows across the site, the ability to position several sizes of window panels increased, and the heat loss in winter and the heat gain in summer decreased which accordingly can lead to financial benefits.

For the Swiss RE Headquarters (Gherkin Tower) in England, the results achieved through Bio-mimicking the glass sponge in Organism level were as the in the following:

The aerodynamic form of the building helps in allowing the wind to flow across the building, which reduces the cladding, and structures’ heavy loads, and also minimizes the amount of wind that turns aside the ground compared with a tower of similar size and shape. Also, it creates different air pressure levels externally which aids in producing natural ventilation for the building. Moreover, the building’s form minimizes the solar reflections and improves the penetration of daylight through the office spaces internally.

**In terms of Energy Efficiency & Heat gain and Loss**

About 40% of the year, most of the mechanical systems of the building have the ability to be supplemented for minimizing the energy consumption as a result of the opening windows in the building’s façade which allows the natural ventilation to be internally flowed in the building (Singh and Nayyar, 2015).

Furthermore, half of the energy consumed by air conditioning systems in the building was being saved as a result of the co-existing of cavities located between the linked radial fingers of each floor which accordingly maximize the financial savings. These cavities are considered to be refreshment areas that distribute the fresh air through the opening panels in the façade (Singh and Nayyar, 2015).

These previous findings strongly support our research hypothesis which is the positive effect of biological modeling on improving the energy efficiency, and optimizing the financial savings as well. Moreover, the promoting of the sustainable construction technologies of buildings through biological modeling is merely pointed to the massive importance of learning natural structural solutions which also helps in serving the architect’s educational library. Biological modeling has shown a noticeable potential in the sustainable constructive technologies’ development. A consistent collaboration between biologists and architects in this field of study is also recommended, as it will assist in guaranteeing the beneficial exchange of knowledge for sustainable advancements to human challenge particularly in increasing the energy efficiency.

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Areas and principles of sustainability in assessing the adaptive reuse of restored Qatari heritage: a case study

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Abstract: In the recent years, due to the oil discovery and exportation, Qatar a small country in the Persian Gulf has typically experienced accelerated and complicated problems of urbanization. Affecting the direction of the rapid urbanization, there is a perpetual dispute, between the construction of new, modern identity and the promotion of traditional architecture as a possible way to establish new relations with the local history and culture. The paper presents some significant examples of adaptive reuse projects, recently completed in Qatar, and shows the increasing demand to strengthen recognition of the local architecture and regenerate the consciousness of the national heritage values. The interventions have been analyzed and compared concerning environmental, socio-economic and socio-cultural aspects derived from the adaptive re-use interventions. Sustainability, as a cultural, social, environmental, and energy-saving value, is one of the most distinguished principles that should be applied to the whole process of heritage restoration. The results show that there exist many common points between the re-use of Qatari heritage, the conservation of ancient natural materials, the promotion of cultural values, the synergism with the landscape, and the adjustment to the climate, to be applied to the restoration strategies and processes compatible with the heritage buildings and the environmental approaches. The concept of sustainability is thus addressed through its meaning of unity and harmony in a broad sense, including materials, use, ecosystem respect, social aspects, investments, costs, although different approaches, strategies and solutions at the urban, architectural, and archaeological scales. The aim of the presented research, which is still under development, is to promote strategies, solutions and good practice that could be adopted in an innovative way for the restoration of the Qatari heritage. The aim is to define an approach that is persistent and will enhance the Arab culture about restoration while respecting sustainable principles.

Keywords: Architectural Heritage, Conservation, Change of use, Sustainability’s Assessment

Introduction

In the Gulf Regions, due to the recent discovery and exportation of oil (1960-1970), the urban growth and expansion of many cities, have generated massive investments. Among the Arab Countries, Qatar is one the most influent protagonist of the scene that has been subjected to an unprecedented economic boom, and its capital, Doha, is becoming a new global city. As a consequence, the rapid urbanization has produced a negative impact both on the spontaneous growth of the city center, and on the preservation and restoration of the national heritage (Salama and Wiedman, 2013).

In fact, in Doha the rapid urban expansion definitively altered the historic center, damaging the remains of the urban fabric and some traditional buildings. Thus a permanent conflict afflicts the growth direction of Doha: on one side the construction of a postmodern global city, represented by advanced infrastructures, innovative materials and spectacular
architectures; on the other hand, the safeguarding of Qatari heritage, reusing the neglected urban fabric, and the abandoned buildings, with the aim of establishing new relationship with the past and the local culture.

Additionally the old urban settlements and the historical buildings present a high degree of flexibility and a functional capacity of adaptation to the environmental, social, economic and cultural conditions of the contexts in which they develop, permitting a more sustainable approach and providing an alternative growth for the city (Di Pasquale and Mecca, 2016).

The United Nations Educational Scientific and Cultural Organization (UNESCO) has described in 2002 the value of the sustainability for safeguarding the heritage of the countries, anyhow without providing clear definitions or rules to be adopted. (Miccoli et al., 2014). There have been always conflicts between the UNESCO heritage buildings and the sustainable developments of growing countries (Wai-Yin and Shu-Yun, 2004), due to the fact that in protected lands there are always overlapping and contrasting laws and regulations at different levels (federal, state and municipal), which form one side enhance the sustainability and in the other contrast the restoration and re-use of the heritage.

The definition of sustainability for heritage reuse is widely debated. In fact, sustainability can be either defined as the successful management of resources to satisfy human needs or by contrast, the sustainability concept of World Heritage re-use is sometimes vague and undefined (Landorf, 2009). Additionally, the meaning of sustainable re-use is challenging to define, because it appears in a vast variety of research areas and might be in contradiction with the basic definition of heritage.

The re-use of heritage buildings, analyzed in this paper, produces economic, environmental and social benefits. Economically, it reduces the amount of money that has to be spent on the new construction on materials, water, and energy. Environmentally, the re-use approach reduces pollution, conserve natural resources and prevent environmental degradation. Socially, the re-use of heritage enhance the values of the local cultural identity which is particularly missed in the Gulf Regions.

The primary purposes of the presented paper are thus the codification of some principles and lessons regarding sustainability as expressed by the recent restoration projects to the Qatari heritage, and the definition of innovative strategies and models for incorporating those principles both in the field of recovery, in the planning and design of sustainable architectures.

Methodology

The research activities started from the analyses and comparisons of significant examples, recently completed in Qatar, of interventions for re-using the national heritage with the aim of codifying technical knowledge pertaining to the adopted materials and constructive techniques which are used in local building traditions, capable of providing principles and guidelines for the planning and design of new architectural structures.

The analyzed restoration projects have aroused the reflection on the exploration of alternative solutions and interventions for integrating functional, formal and technological choices with the sustainable development of Qatari urban center and peripheral areas. The subject of re-using the architectural heritage, widely explored in the past for its cultural value, has been the object over the past decade of a renewed interest, especially in terms of the use of bio-climatic and passive low-cost solutions (Asquith and Vellinga, 2006), which
today are more easily monitored and assessed through the use of control systems and the dynamic simulation of the energy performance of the buildings approach.

The complex system of traditional knowledge related to the buildings’ construction, that is usually conserved and maintained by local communities, and belongs to a broader universe, constituted by specific "worldviews": oral traditions and expressions, knowledge and practices linked to traditional crafts, social customs, ritual and festive events, in other words the intangible heritage which characterises a human group. These systems of knowledge, so rooted in the Qatari culture (Al-Kholaifi, 2006; Jaidah and Bourennane, 2009), constitute some of the essential socio-cultural values that were adopted in assessing the sustainable approach conducted during the conservative interventions for re-use.

In fact, for the codification of the lessons transmitted by the restoration interventions, we have classified the principles according to three areas of interest of sustainability: environmental, socio-economic and socio-cultural.

Analysis of the recent sustainable restoration projects

The adopted approach for the assessment and codification of the data provided by the comparison between the selected examples of restoration projects in Qatar (cases study) have provided a more detailed classification of the main principles according to three areas of interest of sustainability.

The criteria for the selection of the analyzed case study and the adoption of the principles of sustainability, derived from the literature review and some interviews conducted with the Qatari governmental Institutions. The analysis and comparison of the collected data on the completed interventions, derived from the qualitative indicators of the primary assessment systems concerning the three selected area of sustainability in construction:

1) Socio-cultural sustainability is the capability to guarantee and increase the cultural diversity, the sense of belonging, the local knowledge, the personal and communal welfare, the recognition of cultural values (both tangible and intangible) and social cohesion.

2) Socio-economic sustainability indicates the capacity of producing and maintaining the maximum level of added value within the region, to emphasize the social welfare.

3) Environmental sustainability refers to the aptitude of the interventions to integrate with the environmental features of a place, limiting the negative impacts, including those related to climate condition and change.

Doha and the value of tradition: safeguarding the Qatari heritage

The rapid growth of Doha in recent years has generated a massive construction of new spectacular architectures but has also negatively affected the development of Doha historic center, demolishing most of the heritage buildings which are the only remaining evidence of the local traditions (Carter, 2012).

Over the past years, the Qatari administrations have given very little value to the cultural heritage, due to the absence of laws and regulations for the safeguard, until as late as 1980. Since then the fast collapse and destruction of many heritage buildings have awakened attention in the conservation of urban and architectural heritage and new laws were defined for safeguarding their values (Emiri Decrees of 2009, Law no. 23 of 2010,
Antiquities Law no. 2 of 1980). In 2005 the Qatar Museum Authority (QMA) and the Private Engineering Office (PEO) new governmental institutions were set up to safeguard and protect the existing heritage. [9]. Thanks to the restrictions imposed by the institutes and regulations, some urban rehabilitative interventions have recently been launched to reduce the massive demolition phenomenon and revitalize the abandoned urban fabric and the neglected heritage buildings by reusing the places with new entertainment functions. We have selected three main categories of sustainable interventions with the aim of providing a complete overview of the status of restoration in Qatar: the urban interventions re-used as new entertainment places, the architectural restoration reused as new cultural places and the archaeological interventions that were mainly re-used as touristic places (Mazzetto and Petruccioli, 2017).

Reuse of urban interventions: new entertainment places

In the category of the urban interventions, we have analyzed the refurbishment project of Souq Waqif (2004-2008) in the historic center of Doha and the adaptive reuse of the Al Wakrah fishermen village, restored and currently used as the new souq. The historic Souq Waqif was built closed to the port, at the beginning of the 20th century, in the city center of Doha. The conservative and typological restoration project was launched in 2004 under the direction of the Private Engineering Office (PEO) and was completed in 2008, with the intention of reducing the worsening deterioration of the heritage buildings and conserving the oldest structures dating from before 1950 (Radoine, 2010). The Souq Waqif intervention of re-use has regenerated a large sector of the historic city center (Figure 1), bringing back numerous traditional functions (commercial) and introducing new uses (exhibition spaces and outdoor gardens).

The second adaptive re-use project of Al Wakrah was completed in 2015 by the Private Engineering Office (PEO). The intervention was about the urban regeneration of the historical fabric of Al Wakrah fisherman village, located close to the ancient port, which was abandoned for many years. The area was then transformed into the new Souq of Wakrah, through an urban reuse project that involved the reconstruction of many collapsed buildings, the removal of disfiguring elements and materials, the adaptation of the premises, and the

![Figure 1. Souq Waqif. Restaurants and shops.](image)
management of new commercial units (Figure 2). In Al Wakrah the substantial identity of the place was maintained with the birth of a new citadel where currently new activities and functions are located, and still, the real cultural and social values are tangible and well preserved.

Figure 2. Al Wakrah Souq. The public spaces for the new entertainment activities designed in the new souq.

Both the two analyzed projects have addressed the qualitative indicators and principles of two main areas of sustainability in restoration. In fact, concerning socio-cultural sustainable aspects, both the interventions have reinforced the sense of belonging to the traditional Qatari places, generating new entertainment functions (souq), that have enhanced the value of the cultural diversity and integration, while promoting the recognition of cultural values. Moreover, from the sustainable socio-economic point of view, both the urban regeneration projects have strengthened the value of the neglected local areas, to assure social welfare.

**Adaptive reuse for architectural interventions: new cultural places**

The growing significance in safeguarding the Qatari heritage has also contributed to the increasing number of restoration projects at the architectural scale, in the last decades. We have compared and analyzed three interventions of adaptive re-use at architectural scale re-used as new cultural places in Qatar.

The Heritage Houses restoration project (2006-2015) (Msheireb Downtown Doha, 2016) was about the re-use of four residential buildings, constructed at the beginning of the 20th century: Mohammed Bin Jassim House (1913), Bin Jelmood House (1924), Radwani House and Company House, located in centre of Doha (Figure 3). The intervention was carried out under the supervision of the Private Engineering Office PEO and the direction of Msheireb Properties Real Estate Company.
Currently, the restored houses host two museums of the oil extraction industry and the slavery period in the region including permanent and temporary exhibitions. Another case study is the adaptive reuse project of the Barzan Towers, completed by Qatar Museum Authority (QMA) in 2015. The towers were used for defensive reasons at the turn of the 20th century. During the restoration works the original function was turned into a new museum. The mosque and the "Majlis" located nearby the towers, were also restored transforming the place in a new cultural center (Figure 4).

With the aim of reusing the abandoned and neglected Al Dakhira Mosque, the conservative works were completed in 2015 under the supervision of the Private Engineering Office. The mosque is currently re-used as a new cultural and religious center. Before the intervention, the walls of Al Dhakhira Mosque were affected by structural cracks and rising capillary damp problems. The external plasters were restored, new aluminum doors and windows were fitted, and the systems were upgraded, to enhance the usability of the spaces and to protect the interiors (Figure 5).
We have compared the sustainable approaches adopted during the restoration projects, for the analyzed three architectural interventions, to show how the socio-cultural sustainability was mainly promoted by re-using the abandoned places as new cultural and museum centers. The aim of the Heritage Houses and the Barzan Towers projects, currently used as new cultural museums, was to wholly preserve the existing heritage buildings, which were in a remarkably deteriorated condition, close to the collapse as a result of the neglect and abandonment during the last decades. In the same way the restoration projects of Al- Dhakhira Mosque and its new function as a cultural and religious center has brought to light, together with the other interventions, the sustainable capacity to address and reinforce the social needs and the sense of belonging, the cultural diversity, the local construction knowledge and the recognition of social cohesion, which derived from the qualitative indicators of the adopted assessment systems concerning the sustainability in restoration.

**Archaeological interventions: new touristic places**

The most interesting archaeological intervention, re-used as a new touristic place, is al Al Zubarah site (Figure 6) (Walmsley et al., 2010). The conservative project and the campaign of archaeological excavations, completed in 2014 by Qatar Museum Authority (QMA), have promoted the collaboration between the governmental institutions, the local community and the universities of Qatar. Al Zubarah was built up in the 11th century AD during the medieval Islamic period, as a commercial city, then it was destroyed in 1811 and later abandoned in the early 20th century. The Archaeological excavations discovered the remains of the ancient Al Zubarah city including the streets, mosques houses, defensive walls, the harbor, and the palace. During the campaign of archaeological excavations, the bases of the buildings brought to light the traditional techniques and the materials used for construction. Al Zubarah is currently a touristic place, provided with facilities and services for visitors and used as an outdoor urban archaeological museum.
The adaptive re-use intervention carried out showed the sustainable achieved results, demonstrating the capacity of the re-use function, to integrate with the environmental features of al Zubarah place, limiting the negative impacts, and addressing the issues on the extreme climatic conditions.

**Results: sustainable approaches in the restoration field**

Analysis of the restoration works made it possible to compare the methods used, providing an updated description of the adaptive reuse practice in Qatar, which is including the adopted principles and areas of sustainability related to the conducted assessment.

The analyzed adaptive reuse projects have often been isolated, and a coordinated plan of all the restoration works, is still missing in Qatar. The analyses were compared in relation to the adaptive reuse, the scale of each project, the type of interventions carried out, the methodology used for upgrading the environmental systems, the materials used, and how the interventions had been completed to enable the buildings and the urban fabric to be brought back into use, showing the different level of contributions in terms of sustainability. The completed works, solutions and strategies were classified into three categories corresponding to the various scales of interventions: urban, architectural and archaeological. The urban category includes conservation and urban regeneration projects, on a large scale. The number of interventions is limited to a few. The architectural category comprises a vast number of conservation projects of small buildings, having different functions and typologies. The archaeological category shows few-unique projects which include both the architectural and the urban scales.

The definition of the assessment principles and strategies was based upon the lessons of the heritage re-use and was defined by the revision of the literature focusing on themes of knowledge and sustainability in restoration, to compare approaches, analyses, and observation and of case studies of heritage buildings. The aim was to codify the local building traditions, capable of providing principles and guidelines for the design of the structures to be reused. In the meantime, the research included the interpretation of old materials, techniques, typologies and the local building culture, exploring the most appropriate solutions and interventions for integrating technological formal and functional proposal of re-use with the sustainable development of the cities.
The subject of heritage reuse, widely analyzed in the past for its cultural value, has been always considered from the sustainable point of view, in terms of using of bio-climatic and passive low-cost solutions, which nowadays are quickly assessed and controlled by innovative monitoring systems and dynamic simulations of the energy performance of the heritage building. Most of the past analyzed researches are based on the selection, adoption, and reuse of sustainable building materials (raw earth, stone, wood or bamboo), on the sustainable systems and technological performances, or on the relationship between the building typologies and the thermohygrometric comfort. However, such approaches, do not consider the social, cultural and economic factors that have determined the development of sustainable, innovative solutions. It this way it was mandatory to adopt a new transversal approach for the codification of the lessons transmitted by heritage buildings, classifying the principles of assessment according to three new areas of interest of sustainability: environmental, socio-economic and socio-cultural. Based on these three areas of interest, the criteria for the definition of the principles of sustainability of heritage buildings and the selection of re-use case studies and strategies, derived from the literature, the research experience and the analysis of the case studies

For each selected intervention five central principles of sustainability were adopted in each area of sustainability to assess the case study. The restoration projects show some specific strategies, and the approach to restoration taken for each intervention was related to the government authorities responsible for the works. The adopted principles of sustainability used for the assessment methodological approach considered also the context in which the project was located, the primary objective of the strategy, the characteristics of the system, its subdivisions and variations in different geographical situations, the contribution in terms of sustainability and the possibilities of re-use the places with new functions. Table 1 and Table 2 document, for each selected case study, the status of the adaptive reuse intervention in Qatar (Table 1) and the adopted assessment systems for the projects (Table 2), describing the features and performance, adopted for environmental, socio-cultural and socio-economic sustainability.

The results show that the taken approach for restoration depended on the existing state of deterioration of the buildings and it was more or less preservationist concerning the new use. For example, the adaptive reuse projects have preserved the existing structures only, in particular for the buildings with a new museum function (the Heritage Houses Museums and the Tower Museum) (Table 1). The intention was to maintain the existing materials as found, without variation. In other adaptive reuse, notably where massive structural consolidation was carried out due to the advanced level of deterioration, some traditional and innovative materials were combined. In the case of commercial and entertainment re-uses, the restoration projects allowed for typological reproduction, providing the upgraded services as required by the new uses. Regarding the sustainable adopted approach, the results show that the categories of urban and architectural interventions have mainly addressed the principles of sustainability about the socio-cultural and socio-economic areas, while the archaeological interventions have focused primarily in the principles and area of environmental sustainability.

Table 1. Schematic comparison of adaptive reuse projects completed in Qatar.
<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>Agency</th>
<th>Project categories</th>
<th>Old use</th>
<th>Adaptive Reuse</th>
<th>Area of Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Souq Waqif</td>
<td>2008</td>
<td>PEO</td>
<td>Urban regeneration</td>
<td>Souq</td>
<td>Commercial - Entertainment</td>
<td>Socio-cultural and socio-economic</td>
</tr>
<tr>
<td>Al Wakrah</td>
<td>2015</td>
<td>PEO</td>
<td>Urban regeneration</td>
<td>Fishermen Village</td>
<td>Commercial - Entertainment</td>
<td>Socio-cultural and socio-economic</td>
</tr>
<tr>
<td>Heritage Houses</td>
<td>2014</td>
<td>PEO</td>
<td>Architectural conservation</td>
<td>Residential Houses</td>
<td>Cultural Museum</td>
<td>Socio-cultural and socio-economic</td>
</tr>
<tr>
<td>Barzan Towers</td>
<td>2015</td>
<td>QMA</td>
<td>Architectural conservation</td>
<td>Defensive structure</td>
<td>Towers Museum</td>
<td>Socio-cultural and socio-economic</td>
</tr>
<tr>
<td>Al Dhakhira Mosque</td>
<td>2015</td>
<td>PEO</td>
<td>Architectural restoration</td>
<td>Mosque</td>
<td>Religious and Cultural Center</td>
<td>Socio-cultural and socio-economic</td>
</tr>
<tr>
<td>Al Zubarah</td>
<td>2014</td>
<td>QMA</td>
<td>Archaeological conservation</td>
<td>Residential</td>
<td>Outdoor Touristic area</td>
<td>Environmental</td>
</tr>
</tbody>
</table>

Table 2. Schematic comparison of areas and principles of sustainability used for assessing the restoration projects completed in Qatar.

<table>
<thead>
<tr>
<th>Areas of sustainability</th>
<th>Principles of sustainability (5 for each area)</th>
<th>A = High</th>
<th>B = Average</th>
<th>C = Low</th>
<th>Urban regeneration</th>
<th>Architectural restoration/conservation</th>
<th>Archaeological conservation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Souq Waqif</td>
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<td></td>
<td>Souq Al Wakrah</td>
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<td>Heritage Houses</td>
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<td></td>
<td>Barzan Towers</td>
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<td></td>
<td>Al Dhakhira Mosque</td>
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<td></td>
<td>Al Zubarah</td>
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</tr>
<tr>
<td></td>
<td>1. To support local autonomy</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. To promote traditional activities</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>3. To optimize construction efforts</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>4. To extend building lifetime</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>5. To save resources</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>6. To protect the cultural landscape</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>7. To transfer construction cultures</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>8. To enhance innovative and creative solutions</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>B</td>
</tr>
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<td></td>
<td>9. To promote tangible and intangible values</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td>B</td>
</tr>
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<td></td>
<td>10. To encourage social cohesion</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>11. To respect environmental context and landscape</td>
<td>C</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>12. For the benefit of natural and climatic resources</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>13. To reduce pollution and materials' waste</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>14. To contribute to human</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

In Doha, a new emergent global city, despite its fast urbanization and modernization, there is a growing need to safeguard the heritage. In fact, the values of local Qatari tradition and the architectural identity are currently facing the risk to disappear because of the latest massive demolitions.

The research presented some significant restoration projects, recently completed in Qatar showing how these adaptive reuse interventions can provide one valid alternative for the growth of the city, respecting and preserving the existing architectural culture and traditions, while addressing the selected principles about the adopted three areas of sustainability. The comparison and description of restoration projects in Qatar show that currently there are various methods for the restoration of architectural, urban and archaeological heritage. The different approaches are imposed by the governmental bodies responsible for the projects. The lessons taught by the Qatari heritage provide innovative answers to some of the social and environmental challenges of the 21st century. Contemporary re-used sustainable architecture should be capable of incorporating proven traditional construction methods and techniques, enhancing them through contemporary means, know-how and technologies.

The complete process of reusing heritage buildings can always be changed by modifying the use of sustainable materials or the adopted methods and approaches for interventions. The standards for the sustainable re-use of heritage are available for almost every type of building, and the standards are continually updated and monitored; covering all phases of the building’s lifecycle. Heritage buildings that have been designed accordingly to sustainable standards have to monitor in the correct application of the sustainable standards. On the opposite Heritage buildings that were built before the adoption of the sustainability standards have to be upgraded in order to meet the requirements. In particular, the re-used heritage buildings, must include a focus on energy efficiency and renewable energy; the efficient use of water; the use of environmental friendly building materials and specifications; a minimization of the waste and toxic chemicals generated in the building’s construction and operations; and a sustainable approach on growth and development. For the sustainable re-use of the heritage, the adopted materials have to satisfy the required standards for health and safety. Not only their cost has to be competitive and environmentally friendly, but, when used correctly, these natural alternatives have to provide strength and durability for many construction materials. The aim is to reduce the negative impact on the environment by using the natural resources more efficiently (e.g., energy, water); enhancing and protecting the occupants and reducing any adverse impacts on their health and well-being.

The principles and indicators of the sustainability of Qatari re-used heritage show the different approaches, strategies and solutions at the urban, architectural, and archaeological scales, described and assessed according to their degree of sustainability and the critical aspects they present.
The research provides a first step in the definition of sustainable and appropriate restoration methods and techniques, design, aimed at planners, architects and local communities, and based upon good experimental, traditional practices with the intention of enhancing the diffusion of Qatari conventional tools and techniques of sustainable construction.

References


Defining the Characteristics of Prefabricated Architecture as an Alternative Sustainable Construction Approach

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Abstract: Increasing population, international economic problems, energy crisis and worldwide environmental problems are considerable issues that are forcing the world to conceive innovative solutions that are fast, feasible, and sustainable. Prefabricated architecture is an architectural approach based on an offsite manufacturing process of building materials, components, or systems which are then installed together to form a larger assembly on-site. Prefabricated architecture is not a new trend; however, it has recently become a popular trend worldwide due to several advantages which promote sustainability such as: the quick construction process and assembly, high quality control, construction waste reduction, modular flexibility, cost reduction, affordability, consistency, improving energy efficiency, and environmental control. Although the various advantages of prefabricated architecture, its practices is still limited. This can be referred to the lack of knowledge about its characteristics and properties. This paper aims at determining the main characteristics of prefabricated architecture as an alternative construction approach that promotes sustainability. This is achieved through a comprehensive critical analysis of existing relevant literature to define these characteristics which include: the different terminologies, scales of prefabrication, sustainability aspects, and structural aspects. Defining these characteristics could facilitate design decision-making for optimum prefabricated buildings practices and push stakeholders to promote this trend and encourage its application.

Keywords: Prefabricated architecture, Scales of prefabrication, Sustainability aspects, Structural aspects

Introduction

Speed of construction, quality control, cost control, improved environmental performance, reducing negative environmental impacts have become critical concerns which building construction industry pays a significant attention on recently. Several studies have shown that the application of innovative prefabricated architecture is considered as a strategy to achieve these goals. Prefabricated architecture have gained a great momentum since early 20th century starting from prefabrication elements (ex. Doors and windows) to prefabricated panels and units and ending with fully finished and furnished units which is ready to be occupies once delivered to site.

However, the main characteristics of prefabricated architecture are fragmented and need to be consolidated. Defining these characteristics can facilitate decision making based on a solid knowledge of prefabricated architecture advantages and disadvantages in order to help in achieving its optimum application.

This paper defines the main characteristics of prefabricated architecture to build a solid base that could guide future applications and practices.
Prefabricated Architecture Terminologies

The prefabricated units are constructed in a remote facility, and then delivered to their intended site of use. Using a crane, the units are set onto the building’s foundation and joined together to make a single building. The units can be placed in different ways and orientations allowing a wide variety of configurations and styles in the building layout.

It is also described as a building construction process which involves the manufacture of industrialized or precast construction components of various dimensions at a factory, before delivery to a construction site for assembly.

Several approaches have been emerged with almost the same concepts and principles of the prefabricated architecture, but yet with different terminologies. A summary of these terminologies, their definition, application, and examples are presented in Table 1.

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prefabricated Architecture/Construction</td>
<td>It is a general term refers to any offsite manufacturing process of buildings or their components before installing them onsite.</td>
</tr>
<tr>
<td>Industrialized Building Systems (IBS)</td>
<td>It is a construction technique emerged in Malaysia in the early 2000’s. It is mainly based on standardizing building components, manufacturing them in a controlled environment (on or off site), transporting, positioning and assembling them into a structure with minimal additional site works.</td>
</tr>
<tr>
<td>Capsule Units</td>
<td>It is a term refers to a prefabricated living space that accommodates the everyday essentials of a person. The replaceable capsule units are prefabricated and assembled in factories and then installed into a concrete core which contains the public utilities as stairs, elevators, plumping and electrical systems.</td>
</tr>
<tr>
<td>Adaptive Structure</td>
<td>It is a design approach based on the adaptability and flexibility concept which makes it possible to continue using the building even if needs have changed. This is the “loose fit, long life” concept that aims at the maximum reuse of the structural components of the building.</td>
</tr>
<tr>
<td>Modular Building/Construction</td>
<td>It is a construction technique in which modules are manufactured in factory with all technical installations contained, and then transported to site ready for occupancy.</td>
</tr>
<tr>
<td>Containers Units</td>
<td>It is an architectural approach which uses shipping containers as a structural module that can be used as one single unit or multiple attached units.</td>
</tr>
<tr>
<td>Modern Methods of Construction</td>
<td>The term firstly defined in United Kingdom to represent the advanced onsite and offsite construction methods that promotes the integration of advanced technology within construction process.</td>
</tr>
<tr>
<td>Mobile/Relocatable/Transportable House</td>
<td>These terms are firstly used in Australia and New Zealand in the 18th century to represent mobile houses which are completely prefabricated offsite and delivered to site as one unit fully finished with all the needed technical installation and furniture.</td>
</tr>
</tbody>
</table>

Table 1: Prefabricated Architecture Terminologies
Scales of Prefabricated Architecture Practices

The scale of prefabrication represents the complexity of prefabricated components of the final product. It should be noted that increasing the degree of prefabrication results to decreasing the degree of on-site construction and the degree of customization and flexibility within the design and execution phases.

Different classification schemes have been developed to describe different scales of prefabrication. A summary of these classification schemes is presented in Table 2.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Bell, 2010</th>
<th>(Boafo, Kim, &amp; Kim, 2016)</th>
<th>(Luther, 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Materials</td>
<td>N/A</td>
<td>Materials</td>
</tr>
<tr>
<td></td>
<td>Component</td>
<td>Component</td>
<td>Panel Systems</td>
</tr>
<tr>
<td></td>
<td>Panels</td>
<td>Panelised Structure</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Pods</td>
<td>N/A</td>
<td>Skeletal Systems</td>
</tr>
<tr>
<td></td>
<td>Modular</td>
<td>Modular Structures</td>
<td>Hybrid Structures</td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>Utilized Whole Building</td>
<td>Cellular Systems</td>
</tr>
</tbody>
</table>

Based on the previous analysis of the different classification schemes, a comprehensive classification scheme is proposed in Table 3 as follows:

<table>
<thead>
<tr>
<th>Scales of Prefabrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
</tr>
</tbody>
</table>

Sustainability Aspects

Prefabricated architecture is considered as a sustainable construction approach due to its different advantages related to cost reduction, energy efficiency, and environmental conservation. There is also a common aspect between prefabricated architecture and sustainable architecture which is the circular thinking approach. Both approached are based on shifting the way buildings are designed and constructed from the “linear system thinking” in which each design discipline works in his own segregated bubble without any integration or coordination with other discipline- towards “circular system thinking” in which all design disciplines coordinate to achieve the efficient building delivery process.

Hence, a range of recent studies have been employed in an attempt to reduce buildings’ impacts on the environment by implementing the prefabricated construction technique.

The previous studies discussed the topic from various points of view such as: the improved efficiency of material consumption of prefabricated construction, the potential benefits in preventing or reducing construction waste, and the embodied energy savings resulting from waste reduction.

Sustainability can be achieved through three main aspects which are: Environmental aspect, Economic aspect, and social aspect. The following part introduces the sustainability aspects of prefabricated architecture via analysing these three main aspects.
Environmental Aspect

The environmental aspects of prefabricated architecture can be described in terms of lifecycle impact analysis. The lifecycle impact of buildings can be analysed through several factors such as: materials and resources consumption, embodied energy, Green House Gases (GHG) emissions, and waste production. The following part presents these environmental aspects:

- **Efficient Materials Consumption**
  Materials consumption, embodied energy, GHG emissions are all indices of how prefabricated architecture impacts nature through its lifecycle. Several studies have investigated these aspects, it was found that prefabricated architecture practices lead to a remarkable reduction in materials and resources consumption, this is due to reducing the materials waste during the construction process in addition to extending the materials lifecycle by using durable, reused, or recycled materials.

  A study was conducted on an eight story high residential building and materials consumptions was investigated and compared with similar conventional construction. The study showed that the prefabricated system resulted in reduced material consumption by up to 78% by weight. It also showed that investigated building reduced the consumption of raw materials by up to 61% by volume compared to conventional concrete structure (Ngo, T., et. Al., 2009).

- **Embodied Energy**
  Embodied Energy is the energy consumed during extraction, processing, manufacturing, and transportation at all stages (Boustead, I. and Hancock, 1979).

  In terms of embodied energy of prefabricated architecture, a study analysed two office buildings one with a structural steel frame and the other with a cast in place concrete frame. The study concluded that the total embodied energy over the building lifecycle is comparable (Guggemos, A.A. and Horvath, A., 2005).

  Another study has shown that the embodied energy of prefabricated steel building greatly increases to above 50% than conventional concrete systems, while in case of prefabricated timber and steel buildings, it increases to about 10% higher than conventional concrete buildings due to the increased energy needed in production, transportation, and construction.

  Accordingly, the total life cycle greenhouse emissions for a 50-year life span have increased by 13% for the prefabricated steel building than the concrete structure. However, more than 80% of this increase is saved back at the end of the building lifecycle due to the durability and the ability to reusing the main structural elements and components in new buildings (Gunawardena, T., et. al., 2011).

- **Waste Reduction**
  Prefabricated architecture promotes waste minimization through transforming from the conventional construction process (which depends on fabrication of all construction elements on site) to a more efficient construction process that depends on fabrication of the construction elements in factory and then transporting them to site to be installed.

  Another study has showed that prefabrication of buildings reduces construction waste by up to 52% which will in turn result in significantly improved energy, cost and time efficiency of construction. (Jaillon et al.,2009)
Economic Aspect

The use of prefabricated architecture with its different levels of prefabrication offers great opportunities to reduce both the direct and indirect cost of the project construction process. The direct cost is the cost that is completely attributed to the production and construction process. The factors that affect the direct cost include Mechanical cost, Material cost, Transportation cost, Labour cost, and Cranes cost.

Shan Zhang and others have investigated the direct costs of prefabricated system via a comparative study with the traditional construction technology to determine the potential of prefabricated system to reduce the cost. The study was based on calculating the direct cost required for precast concrete wall panel as a case study and comparing it with the direct cost required for the traditional brick wall.

The study has shown that the prefabricated system has a higher mechanical and material costs (124.3% higher mechanical cost and 134.6% higher material cost), while it has a lower labour cost (86.5% lower labour cost). The overall direct cost of the precast concrete wall panel is not much higher (105.5%) than the traditional brick wall. (Zhang S., et al., 2014)

On the other hand, prefabricated architecture approach can positively affect the project cost through:
- Reducing construction time and accordingly faster investment reverting
- Increasing the productivity of the site works
- Reducing site waste
- Reducing site supervision
- Eliminating changes during construction and reducing reworking (Langdon & Everest, 2002)

Social Aspect

Adopting prefabricated architecture approach promotes social sustainability aspects as it has gained social acceptance and popularity through the application of three main concepts:

• User Perception
Prefabricated architecture enhances high living standards and quality of life as a more advanced construction technique.

• Flexibility
Prefabricated architecture is characterized by being responsive to individual needs by enabling users to change some conditions without changing the basic system. This has a great impact not only to fulfill their present needs but also to comply with future changes.

• Affordability
As mentioned in the economic aspect, prefabricated architecture can reduce the project total cost, reducing unit’s price, and making it affordable and more socially accepted. One of the benefits of constructing affordable units is to use them a potential alternative for slums and informal settlements to achieve a sustainable built environment (D., Moses, 2014)

Structural Aspects

Prefabrication can be applied on many aspects of the building. The structural elements of the building can be prefabricated as well as the building skin or façade. Also the technical installations of the building such as the electrical, plumbing, and HVAC installations can be produced and assembled in factory and ready to be installed onsite. Even the furniture and
appliances can be prefabricated and sometimes already installed in building units in case of prefabricated modules.

A summary of prefabrication construction systems and production methods is introduced in Table 4.

| Table 4: Structural Aspects of Prefabricated Architecture |
|---------------------------------|---------------------------------|---------------------------------|
| Ref | (Okodiah, 2012) | (DEPLAZES, 2005) | (Smith, 2010) |
|---------------------------------|---------------------------------|---------------------------------|
| Prefabrication Construction Systems | • Large-panel systems  
• Frame systems  
• Slab-column systems with walls  
• Mixed systems | • Non-loadbearing elements – facades  
• Self-supporting elements – room units  
• Loadbearing elements – floor, wall and roof  
• Loadbearing elements – room segments  
• Loadbearing elements – room units | • Structure:  
- Load-bearing systems  
- Skeletal systems  
- Space frames  
- Diagrid |
| Production Methods | • On-site Prefabrication  
• Off-site Prefabrication  
• Composite (a combination of both) | • Manual prefabrication  
• Mechanized prefabrication  
• Partly manual /partly mechanized prefabrication | • Manufacturing  
• Fabrication |
| | | | Services:  
- Electrical installations  
- Plumbing installations  
- HVAC installations  
- Equipment  
- Furniture |

Table 4 shows that different classifications have been proposed to define the prefabricated architecture construction systems. The first study has categorized it to four types according to the type of load-bearing structure, while the second study has classified it according to the use of the prefabricated elements.

Ryan E. Smith introduced a comprehensive classification which considers also the used materials and the function of the prefabricated element.

On the other hand, Prefabrication production Methods has been investigated in different studies. Almost all the studies agreed on three methods of production: Manual, Mechanized, and Composite. However, they presented these methods in different terminologies. Hence, a comprehensive classification is proposed in Table 5 as follows:
Table 5: Proposed Classification of Structural Aspects of Prefabricated Architecture

<table>
<thead>
<tr>
<th>Structural Aspects of Prefabricated Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabrication Construction Systems</td>
</tr>
<tr>
<td>Self-supporting Element</td>
</tr>
<tr>
<td>-Rooms</td>
</tr>
<tr>
<td>-Units</td>
</tr>
<tr>
<td>-Pods</td>
</tr>
<tr>
<td>-Containers</td>
</tr>
<tr>
<td>Structural Elements</td>
</tr>
<tr>
<td>-Main</td>
</tr>
<tr>
<td>-Load-bearing systems</td>
</tr>
<tr>
<td>-Skeletal systems</td>
</tr>
<tr>
<td>-Space frames</td>
</tr>
<tr>
<td>-Diagrid</td>
</tr>
<tr>
<td>-Wall</td>
</tr>
<tr>
<td>-Slabs</td>
</tr>
<tr>
<td>Structural Elements</td>
</tr>
<tr>
<td>-Main</td>
</tr>
<tr>
<td>-Wood panels</td>
</tr>
<tr>
<td>-Glass panels</td>
</tr>
<tr>
<td>-Metal panels</td>
</tr>
<tr>
<td>-Stone panels</td>
</tr>
<tr>
<td>-Precast cladding composite</td>
</tr>
<tr>
<td>-Secondary</td>
</tr>
<tr>
<td>-Electrical installations</td>
</tr>
<tr>
<td>-Plumbing installations</td>
</tr>
<tr>
<td>-HVAC installations</td>
</tr>
<tr>
<td>Non-structural Elements</td>
</tr>
<tr>
<td>-Skin</td>
</tr>
<tr>
<td>-Equipment</td>
</tr>
<tr>
<td>-Furniture</td>
</tr>
<tr>
<td>Production Methods</td>
</tr>
<tr>
<td>Manual prefabrication</td>
</tr>
<tr>
<td>Mechanized prefabrication</td>
</tr>
<tr>
<td>Composite</td>
</tr>
</tbody>
</table>

Conclusion

This paper provided a comprehensive literature analysis of prefabricated architecture to define its main characteristics.

Four main characteristics were found essential to be defined to promote prefabricated architecture practices which are: Different terminologies, different scales of prefabrication, sustainability aspects, and structural aspects.

Different terminologies of prefabricated architecture were found to be used worldwide. These different terminologies have been investigated to figure out the common core concepts among them.

Also different classification schemes of prefabrication scales were found in the existing literature. The different schemes were analysed and a proposed one was set to define the scales of prefabricated architecture practices starting from low level of prefabrication such as prefabricated material and ending with high level of prefabrication such as a whole prefabricated unit.

Sustainability aspects of prefabricated architecture were also examined through investigating environmental, economic, and social aspects. This helped in approving that prefabricated architecture can be considered as a sustainable alternative to the conventional approaches.

Finally an analytical review of the relevant existing literature was done to define the main structural aspects of prefabricated architecture. A proposed structural classification was provided based on two main aspects which are: the fabrication construction system and construction methods.

Figure 1 summarizes the concluded characteristics of prefabricated architecture as follows:
Figure 1: Characteristics of Prefabricated Architecture
References


Swedberg C. (2007). Gammon Steel Tracks Modular Components For Buildings


Procédia Engineering, 14, 1590-1598

BAKE-OUT THE VOLATILE ORGANIC COMPOUNDS FOR RESIDENTIAL BUILDING – PRE OCCUPANCY- IN SUMMER AT EGYPT

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Abstract: The main objective of this study is to come up with a new method to extract the Volatile Organic Compounds (VOCs) emission for indoor spaces. Computational Fluid Dynamics (CFD) will be used in simulation to assess the Indoor Air Quality (IAQ). ANSYS FLUENT V.14 is the software used to simulate the VOCs emission using Solar Radiation Model, and Chemical Species & Transport Model. During simulation the conservation equation for momentum, energy and mass fraction for each VOC will be taken into consideration. The numerical model applied in this study are, two small spaces on the south facade orientation. These spaces are different in volume, they exist on the seventh floor of a residential building that’s eight stories high. The two spaces have glass windows of 3 mm thickness which are completely sealed from all sides, creating greenhouse effect for understudy, during summer time. The hot air which is comprised inside the space is used to bake-out the undesirable VOCs on the varnished surfaces. The results of this study show that the extracted VOCs concentration level are much higher not only in the larger volume but in the elevated temperatures as well, which leads to exceeding threshold limit values of LEED V.4 for Homes.

Keywords: Bake-Out, Indoor Air Quality (IAQ), Volatile Organic Compounds (VOC), Computational Fluid Dynamic (CFD), Emission and Concentration.

1. Introduction

Most people believe that buildings can protect their users from outdoor air pollution, however in many cases indoor air may be more polluted than outside air. The indoor spaces may contain different kinds of pollutants and containments which can be classified into different categories; inorganic pollutants ‘ e.g. Carbon Dioxide (CO₂), Carbon Monoxide (CO), Nitrogen Dioxide (NO₂), Sulphur Dioxide (SO₂), Ozone’, organic pollutants ‘ e.g. Volatile Organic Compounds (VOCs), Formaldehyde (HCHO), Pesticides, Poly Nuclear Aromatic Hydrocarbons, Polychlorinated Biphenyls’, physical pollutants ‘ e.g. Asbestos, man-made mineral fibers, Radon’, and Radioactive pollutants, biological agents ‘ e.g. fungi, bacteria’, etc. (Godish, 2001) (Ilgen, et al., 2001) (Pośniak, et al., 2005) (Mamdouh, 2006) (Alves, et al., 2013).

Different studies have emphasized the negative effects of inhaling these VOCs on building users. The inhalation can cause inflammation of mucous membranes, irritation, headache, asthma exacerbation and even chronic effects ‘ e.g. respiratory system, circulatory system, and central nervous system diseases, organs dysfunction, and cancer’ (Shirley, 2001) (Toxipedia, 2014).

Restrictions are set by several rating systems to prevent the VOCs from exceeding the allowable limits after the installation as reported in BREEAM’s standard (BREEAM, 2014), LEED V4’s standards (USGBC, 2014) and etc. while the Egyptian rating system ‘Green Pyramid Rating System (GPRS)’ did not consider the importance of these regulations and standards.
Here is an example of non-green product that has exceeded the limits of the VOCs emissions as shown in table 1.

<table>
<thead>
<tr>
<th>Point of comparison</th>
<th>Styrene</th>
<th>Toluene</th>
<th>Xylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOCs emissions in mg/m³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOCs emissions in ppm</td>
<td>2022</td>
<td>1043</td>
<td>390</td>
</tr>
<tr>
<td>VOCs content</td>
<td>15 % of Styrene</td>
<td>29 % of Toluene</td>
<td>22 % of Xylene</td>
</tr>
</tbody>
</table>

The VOCs emission is significantly affected by the environmental factors (Clausen, et al., 1991) (Shirley, 2001) (Mamdouh, 2006) (Jarnstrom, et al., 2006). It increases as the air temperature (Stuart & Chi-ung, 1995) (Valicenti & Wenger, 1997) and relative humidity (Tuomainen & Pirinen, 2002) increases, contrariwise it decreases as the air flow rate increases (Tuomainen, et al., 2001) (Minami, et al., 2002). Different researches confirmed that the impact of the three environmental factors with the above specified setting, can decrease the VOCs emissions for any installed new materials (Haghighat & De Bellis, 1998) (Godish, 2001) (Sun-sook, et al., 2008).

Various methods are used to get rid of undesirable VOCs, but the most effective method is Bake-out. Bake-out technology has been developed and conducted in buildings at pre-occupancy stage. The theoretical concept of the bake-out is to release the VOCs from the material into the indoor air by raising the air temperature. The elevated temperature accelerates the diffusion of VOCs into air, meanwhile it decreases the amount of VOCs adsorbed by the material. The duration for the bake-out process takes seven to thirteen days at temperature range from 30°C to 40 °C (Chiang , et al., 2001) (Wiglusz, et al., 2002) (Kim & Kim, 2005) (Zhang, et al., 2007) (Choi, et al., 2010).

Several experiments show the side effect of the bake-out technology; deformed wooden furniture while releasing the VOCs, and this phenomena is due to; specific heat capacity and thermal mass for each wooden material (Kang, et al., 2010) (Lee, et al., 2015), that can cause damaging due to the high temperature and dehumidification technique (Girman, et al., 1989). Fig. 1: shows the damaging of the wood during the bake-out.

Fig. (1): The wood is buckling and swelling during the bake-out (James, 2014)

Accordingly, the aim of this research is to verify the impact of the bake-out process via employing the solar radiation for a newly painted apartment at pre-occupancy stage in Egypt.
2. Modelling Of Volatile Organic Compound Concentrations:

The development of the numerical model is based on VOCs transport and diffusion in the indoor air. As a result, the main hypotheses of the CFD model are the following:

- Mixture air-VOCs, incompressible Newtonian fluid.
- No chemical reaction between the species of the mixture.
- Insignificant heat and mass transfer interactions within the mixture.
- VOCs, ideal gas law formulation ‘based on the mixture temperature and the mass fraction of each species ‘air and VOCs’.
- Specific heat capacity of mixture air-VOCs, mixing law formulation ‘depending on the mass fraction average of the species, air and VOCs, heat capacities’.
- Thermal conductivity and viscosity of mixture air.
- Diffusion coefficient of VOCs in air, constant values; based on data extracted from the literature (Teodosiu, et al., 2017).

Based on the above assumptions, the transport and diffusion phenomena of VOCs are taken into account in the CFD model, by means of conservation equations of the mass fraction, written for each VOC that is intended to be considered in the simulation; eq. (1) illustrates this correlation. Mass diffusion in laminar flows; where, $J_i$ is the diffusion flux of species $i$, which arises due to gradients of concentration and temperature. By default, ANSYS FLUENT V.14 uses the dilute approximation called ‘Fick’s law’ to model mass diffusion due to concentration gradients, under which the diffusion flux can be written as

$$J_i = -D_{i,m} \nabla Y_i - D_{T,i} \frac{\nabla T}{T}$$  \hspace{1cm} (1)

Here $D_{i,m}$ is the mass diffusion coefficient for species $i$ in the mixture, and $D_{T,i}$ is the thermal (Soret) diffusion coefficient.

2.1 Solar Load Model

ANSYS FLUENT V.14 provides a solar load model that can be used to calculate radiation effects from the sun rays that enter a computational domain. The solar load model includes a solar calculator utility that can be used to determine the sun position in the sky for a given time-of-day, date, and geographical location. Two options are used: Discrete Ordinates (DO) irradiation and solar ray tracing. Discrete Ordinates (DO) can be used to solve the radiative transfer equation for a finite number of discrete solid angles, each associated with a vector direction fixed in the global Cartesian system ‘x, y, z’. While solar ray tracing can be used to predict the direct illumination energy source, that results from incident solar radiation.

2.2 Case study: Zero Ventilated Room

The numerical models presented above are applied in two new spaces chosen randomly for a one day study on the 21st of August 2017 in Giza City, in Egypt. The two spaces are fully cladded using cellulose-varnished wood panels, their dimensions are ‘3.50 m * 4.00 m * 3 m’ and ‘3.35 m * 5.80 m * 3.00 m’ which cleared in the below figures from (2) to (5), Salon (2) was larger in volume than Salon (1) which is $58.29 \text{ m}^3 > 42 \text{ m}^3$, the two apartments were located on the seventh floor of an eight-story building. The green-house effect was achieved through a windows openings of clear glass window which can emit 84% of the longwave and far-infrared that can penetrate the space, gaining heat from the sun (EWC, 2018), the two windows have dimensions “1.15 m * 1.30 m” and “1.20 m * 1.30 m” oriented towards the south. Air temperature varied throughout the day depending on the sun position, while the air flow rate was almost constantly Zero meter/ second as modeled in ANSYS FLUENT V.14.
The room is formed from a brick wall of 25 cm thick for the outer-wall, and 12 cm thick for the indoor walls, with finishing layers of cement and plastic paint as cleared in figure (6). The ceiling and floor have the same layers; ceramic tiles, cement, sand and reinforced concrete and cleared in figure (7). Finally, the window has a simple wood connections with a clear glass of 95% of the total opening area as cleared in figure (8). All the indoor walls including the door are adiabatic, meanwhile, the window, absorb solar radiation and permit solar rays respectively, increasing air and surfaces’ temperature.
This simulation is based on an assumption, that all indoor surfaces; floor, walls, and ceiling, have Zero VOC’s emission before the installation of wood panels on. Cellulose varnish is used to coat the wooden panels of 5 mm thickness which are installed and cladded on the walls, ceiling and floor as sketched in figure (9). The assessment of IAQ in the room was carried out with consideration to the CFD model of the indoor levels of the following three VOCs: Xylene, Styrene, and Toluene. Consequently, the implementation of the CFD model requires in this case, three supplementary equations expressing the conservation of mass fraction for each of the three VOCs; ‘Xylene, Styrene and Toluene’. The values of the diffusion coefficient of each VOC, is required in the conservation equations specified in Table 2 (New Jersey Gov., 1985).

<table>
<thead>
<tr>
<th>VOC</th>
<th>Xylene</th>
<th>Styrene</th>
<th>Toluene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion Coefficient $\times 10^{-6}$ (m$^2$/s)</td>
<td>7.5</td>
<td>7.1</td>
<td>8.7</td>
</tr>
</tbody>
</table>

The numerical models developed as specified above was built using a finite-volume, Navier–Stokes solver ‘ANSYS FLUENT, V. 14’. Meshing generation is a critical stage for any CFD application, since, it can tremendously influence the accuracy and the turnaround time of the CFD simulation. The mesh is used to analyze fluid flows, in which the flow domain is split into smaller subdomains. The governing equations are then discretized and solved inside each of those subdomains. The mesh quality is influenced by several factors most importantly; Skewness and aspect ratio. Skewness determines how close to ideal equiangular quad. Its value for the examined rooms ranges from 0 to 0.000555 which means it has an excellent range of cell quality. Meanwhile the aspect ratio; is the ratio of the longest edge length to the shortest edge length, ranging from 1.1548 to 319.249 which lies within a good range; not exceeding 1000.

3 Method

Most experiments in the field of environmental studies is preferred to be in-situ, however, in this case, the equipment is not available. Simulation was carried out to evaluate the Indoor Air Quality, via Computational Fluid Dynamics technique (Stathopoulou & Assimakopoulos, 2008) (Corgnati & Perino, 2013) (Ruining, et al., 2014) (Li, et al., 2014) in ANSYS FLUENT.
Three softwares were used in this simulation process; Autodesk Autocad, Pointwise V17.2R2, and ANSYS FLUENT V.14. AutoCAD ‘2D & 3D drafting and drawing’ were the basic tool to draw and define the boundaries of the examined room. Pointwise V17.2R2 is a meshing tool, and was used to split the volume of any domain into equally sub-domain taking in consideration the value of Y+. ANSYS FLUENT V.14 was used to simulate the solar load radiation and Chemical Species & Transport Model.

4 Results and Discussion:

The total duration of the bake-out process ranged from seven to thirteen days. The used model for this simulation is ‘static’ and not ‘dynamic’, which means that simulation is done throughout the hours of a typical day and only one iteration is representing the whole simulation for the ranged duration of the baking-out. The experiment was on the 21st of August, 2017 and readings were taken in the centre of the room, at 1.5m height from finish floor level. Table 3 shows the impact of sun rays penetration for the two spaces for one hour before and after the peak hour, as a sample. Graph ‘1’ demonstrates the indoor air temperature for the two spaces respectively, a steady increase of air temperature throughout the day from 28.1°C and 28.5°C until it reaches its peak of 36.4°C and 38.4°C at noon - that is when the highest solar insolation and direct penetration of sun rays through the window takes place - following a steady decrease down to 28.1°C and 28.5°C by the end of the day. All the measurements of indoor air temperature were calibrated using HOBO data logger in site at 21th of August 2017, while the simulations itself were took place at 18th of April 2018.

<table>
<thead>
<tr>
<th>Table (3): Air temperature for the two room in Celsius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>10 AM</td>
</tr>
<tr>
<td>12 PM</td>
</tr>
</tbody>
</table>
The impact of gaining heat energy from solar radiation can increase the indoor air temperature in which the heat is transferred by convection to all the walls, ceilings and floors. Table ‘5, 6, and 7’ are the output simulations for Styrene, Toluene and Xylene for one hour before and after the peak hour, as a sample. The VOCs were diffused into the room in different directions, however, some of them accumulated at certain points by buoyancy force due to difference in densities. The output simulations are in K.mole/m$^3$ and are converted to µg/m$^3$ to be easily compared with international standards. Table 4 shows the maximum allowable Total VOCs exposure in indoor spaces and is set by various Rating System Tools.

<table>
<thead>
<tr>
<th>VOC</th>
<th>Permissible exposure limits – PELs (µg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEED V.4</td>
<td>500</td>
</tr>
<tr>
<td>BREEAM</td>
<td>400</td>
</tr>
<tr>
<td>DGNB</td>
<td>500</td>
</tr>
</tbody>
</table>
Table (5): ANSYS FLUENT’s simulation of Styerne emissions for both of the two spaces

Table (6): ANSYS FLUENT’s simulation of Toluene emissions for both of the two spaces
Three VOCs were simulated separately along the day; Styrene, Toluene and Xylene. The below graph (2) are the sum up of all VOCs to be compared with LEED V.4 for Homes which is the most common used rating system all overall the world for the VOCs limitation for indoor air containments.
Graph (2): TVOCs measurements at centre of the two spaces

Graph (2) demonstrate the impact of increasing the indoor air temperature, which can change the value of the Total VOC’s concentration throughout the day. The non-green product which is used for varnishing wood panel for both the two spaces was exceeded the permissible value of TVOC along the day which is namely more than 500 µg/m³, as shown in the highlight dashed line in the graph.

The values of concentration emissions for Styrene`s, Xylene`s, and Toluene`s that exist in the non-green product were very high along the day due to the high percentage of solid raw material in the varnish for each VOC. Also, it was noticed that the degradation values of styrene`s and Xylene`s concentration emissions were equal to the primitive value due to the high thermal conductivity of Styrene, and high molecular weight & Specific heat of Xylene. While the Toluene`s concentration emissions was less than the primitive value due to the high of mass diffusivity.

The solar radiation and their impacts of increasing the indoor air temperature and the air convection which can change the value of TVOCs concentration emissions throughout the day. The non-green product showed that the TVOCs` emissions concentration value had steady increase for the two spaces (Salon (1) and Salon (2)) respectively, 926.9 µg/m³ and 933.3 µg/m³ until it reached its peak of 932.3 µg/m³ and 939 µg/m³ at noon, following a steady decrease down to 926.4 µg/m³ and 932.8 µg/m³ by the end of the day.

5 Method Verification and Result Validation

The application of the CFD model, proposed in this study draws a conclusion for the VOCs concentration for indoor spaces. The results of this study show that the extracted VOCs concentration level are much higher not only in the larger volume but in the elevated temperatures as well when the two spaces compared, which leads to exceeding threshold limit values of LEED V.4 for homes. This methodology gives the opportunity to overcome the difficulties facing the users in the site. This numerical model allows researchers interested in the same field to deduce the VOCs concentration in a comprehensive way, which, makes it possible to assess the levels of VOCs near the occupants. The study of the VOCs can be extended for other elements in indoor spaces or another building types.
The output results seem rational that VOCs concentration levels increases with the increase of indoor air temperature and the volume too, which shows the method verification using ANASYS FLUENT V.14 and validation of results. At last, the futuristic studies must cover the neglected variables of exchange the air flow for indoor spaces.

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[Accessed 28 4 2018]


Housing Affordability and Contemporary Construction Systems in Egypt: Simulating the Influence of Insulated Concrete Forms

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Abstract:
This paper discusses the shortage of affordable housing addressed to low income groups in Egypt and illustrates the role that contemporary construction systems such as Insulated Concrete Forms (ICF) can play to improve affordability. The paper starts by defining the problem of housing affordability, and then analyses the gap between housing supply and demand. The study criticizes the use of conventional construction for the past decades to meet housing needs with limited exposure to contemporary building technologies experimented worldwide to attain sustainable affordable housing. The paper investigates ICF as a viable system in affordable housing in Egypt. Recently, ICF has been used in some projects and is gaining local popularity because of its competitive construction cost, time and quality. After the theoretical part of presenting the research problem and the overview of ICF, the paper applies a simulation of ICF system on the current Social Housing Project in Egypt ending in 2020 to study the influence of using ICF on the architectural and economic aspects of the project. Based on the findings, ICF can enhance housing affordability by targeting lower income beneficiaries with the same allocated budget, and can eventually decrease the gap between affordable housing’s supply and demand.

Keywords: Housing Affordability, Construction Systems, Social Housing, Insulated Concrete Forms

Introduction

The population of Egypt increases by about two million inhabitants each year (CAPMAS, 2017); this increase includes a majority of families who cannot afford convenient shelters. The government tries to provide a large number of subsidized housing units each year but falls short beyond the rates of the growing population, especially the low-income groups. This results in a continuous gap between affordable housing supply and demand. Lack of affordable units drives poor and middle-income families to join informal settlements, while others accommodate bleak shelters located in graveyards, roof tops and in-between spaces.

The gap between housing supply and demand in Egypt has always been encountered using mass housing projects subsidized by the government (The World Bank, 2007). For decades, these projects have been constructed using conventional methods with limited exposure and experimentation of other methods. Meanwhile, new construction systems are investigated around the globe in attempt to minimize construction cost and time, maintain a good quality, and attain a better environmental impact.

Insulated Concrete Forms (ICF) construction is one of the trending methods used nowadays in many developed and developing countries, and started being manufactured in Egypt. The paper investigates the role ICF can play to improve housing affordability by making more Egyptian poor families enter the market through low-priced units in mass-housing projects if this technology is used.

Housing Affordability Status in Egypt
Experiments on affordable housing go back to the 1940s and beyond in Egypt. Led by pioneer architects such as Hassan Fathy in New Gourna village, he was aware of the necessity to radically change the spatial organization and building structure of this prototype of housing to make it affordable together with invigorating community efforts to create their own self-help projects (Fathy, 1969). Unfortunately, Fathy’s use of mud-bricks, domes and vaults, despite originality, was not developed enough for mass housing purposes; it wasn’t appropriated to the increasing demand for multi floor housing. Internationally, Fathy’s approach was celebrated and backed by other subsequent efforts in Latin America and South-East Asia for years to come as clear from the work of Charles Correa, Balkrishna Doshi, and Alejandro Avarena (Vale et al., 2014; Doughtery, 2018).

In Egypt, mass housing in concrete forms is foreseen as the modern outlook that many Egyptians aspire to afford and build as manifested in the informal settlements that spread widely since the President Gamal Abdel Nasser’s era post-1952 (Rageh, 2007). The study of housing affordability in Egypt is however impervious and inaccurate due to scarcity of data available from governmental organizations, the speculative nature of information, and lack of depth in the study of the topic.

To overcome this methodologically, the paper assesses the current problem of affordability in Egypt through the study of the Affordability Index as well as the study of housing supply and demand. These two aspects of affordability are indicators of the magnitude of the problem in Egypt. Subsequently, the research extrapolates the expenditure limit that poor families can afford to spend on housing based on the available data on poverty and the global perception of housing affordability.

**Affordability Index**

One key indicator used to categorize the status of housing affordability across countries is the Affordability Index (AI). The numeric value assesses the housing pricing in relation to average citizens’ income (Numbeo, 2018). It calculates both buying and renting prices in relation to the average income of the population regardless of the concentration of wealth amongst the privileged classes. Nonetheless, despite its limitations it remains indicative of the issue. Egypt’s Affordability index is 0.48, which is below the minimum affordable standard of 1.0. In a survey that included 89 countries, the table below shows the Affordability Indexes in Egypt ranked as 77 in relation to Saudi Arabia ranked as number 1, and Ukraine ranked 89 and last, according to Numbeo in 2018.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Price to Income Ratio</th>
<th>Affordability Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Saudi Arabia</td>
<td>2.79</td>
<td>5.03</td>
</tr>
<tr>
<td>77</td>
<td>Egypt</td>
<td>12.68</td>
<td>0.48</td>
</tr>
<tr>
<td>89</td>
<td>Ukraine</td>
<td>18.21</td>
<td>0.26</td>
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The previous table marks the existence of a housing affordability problem in Egypt. Moreover, Affordability Index does not consider other influential dimensions such as the distribution curve of units across the low-income families. The index inherently assumes that governments of all countries distribute units similarly and there is unequivocal distribution of income across social classes. In reality, there is politics involved and there is a discrepancy inside each country and how mass housing units serve the social class pyramid.
A further study is needed to analyze the relative deviation between country’s supply and demand in relation to the corresponding groups of citizens to show which segments of the society, race, gender and geography, suffer most from affordable housing deprivation and which segments, if any, have the power to acquire more than one housing unit for future investment purposes.

**Housing demand and supply**

The second indicator of the status of housing affordability in Egypt is the shortage of housing supply. The housing backlog, as estimated by the Ministry Of Housing, is up to three million units (The World Bank, 2015). Egypt requires approximately 300,000 new housing units per year to accommodate newly formed households plus an additional 254,000 units per year to gradually deal with the shortage of housing over the past five years (Reuters, 2015). There is no data available concerning housing demand in Egypt but the housing plans announced by the Ministry of Housing every five years for both public and private sectors are considered the indicator of housing demand in Egypt.

It is noticed, through the study of the numbers of housing units implemented since the 1980s until 2012 by both public and private sectors, that there is a continuous gap between the number of housing units planned and what was actually built (Fahmi et al. Sutton, 2008). This gap reflects unrealistic predictions, overestimation of the capabilities of housing supply mechanisms and unsuccessful project management. The gap also raises some questions concerning the efficiency of construction methods of housing projects. The following graph shows the number of housing units executed by both public and private sectors in five-year intervals in relation to the total number of planned housing units in the same period according to the official numbers declared by the Central Agency for Public Mobilization and Statistics, the Ministry of Housing, and the World Bank.

![Figure 1 Public and Private Sectors overall planned and executed number of housing units by Author based on official reports (Central Agency for Public Mobilization and Statistics, 2014), (The World Bank, 2007), (Ministry of Housing, Utilities and Urban Development, 2005)](image)

In the most recent CAPMAS’s statistical data on housing in 2017, representing the data on buildings collected in 2016, it shows that there are thirteen million vacant units in Egypt, out of a total of thirty-six million residential units all over the country. This means that about than 35% of the housing units are empty (Central Agency for Mobilization and Statistics, 2017). Twenty-five per cent of the units are vacant because they are not officially sold yet. While around 8% of the units in Egypt are empty because the owners have another
residence, while 3% of the units of the units in Egypt are vacant because owners live abroad (Central Agency for Public Mobilization and Statistics, 2017).

However, all these vacant units cannot be used for low income housing under the current conditions, because people who possess vacant units belong to high and upper middle income groups, hence low income families cannot afford to buy or rent these units (Ghannam, 2002). Moreover, units controlled by old rent laws cannot be used under current legislations governing their rents and radical changes in regulations have to be undertaken to solve the rent control problems. Consequently, most of these empty units will be beyond the capabilities of the poor if offered at fair market prices (General Organization for Physical Planning, 2014; General Organization for Physical Planning, 2012; Rageh, 2007). For the aforementioned reasons, despite the excess of vacant units, the provision of affordable mass housing for low income groups is still crucial at least for the time being; it should be provided with parallel long term legislative reform to gain some balance in the housing market.

**Affordability limits**

The data on Affordability Index and housing supply and demand refer to the problem of housing affordability with good depth but they couldn’t define affordable payment limits for poor families for housing acquisition. This part derives the limits of affordability of poor families based on the available data of poverty percentages, income and expenditure data of different economic groups. The research is deriving though analytical study the affordable amount of money spent by poor Egyptians on housing. Through the study of expenditure schemes for each economic group, the Central Agency for Public Mobilization and Statistics’ published statistics on expenditure data stated that all economic groups have similar expenditure on housing. All economic groups spend nearly 15% of their income on housing (Central Agency for Public Mobilization and Statistics, 2014).

Official reports state that the poor households represent about 26% of the population (The World Bank, 2015). Based on studies conducted by the Central Agency for Public Mobilization and Statistics (CAPMAS) on a sample of economic groups found that a percentage of 27% of the families is located in the house-hold economic group that spends L.E 17,000 – 20,000 per year (Central Agency for Public Mobilization and Statistics, 2014). Roughly speaking, this economic group can be considered the datum of poverty for Egyptian families; thus all house-hold economic groups who spend less than L.E 20,000 per year can be considered below the national poverty line and they are the scope of this research.

Regarding the global perception of housing affordability, the UN High Commissioner for Human Rights alleged: “Housing is not adequate if its cost threatens or compromises the occupants’ enjoyment of other human rights.” (United Nations, 2014). Moreover, the United Nations Human Settlements Program (UNHABITAT) states that access to adequate housing means that housing expenditures do not take up an undue portion of households’ income (United Nations Human Settlements Program, 2004). In light of these definitions of poverty, it is concluded that poor families should be spending around 15% of their income on housing, and this should be the new datum considered by housing projects planners when targeting their housing projects’ beneficiaries.

In light of the studies illustrated in the following table, considering the poorest 25% of the population to be the poor as defined by most economists and official reports, it is shown that the poverty line is located around the families who spend less than 20,000 EGP per year. According to affordable percentage to be spent in housing according to people’s
expenditure schemes, it is deducted that a family can pay a maximum of 3700 EGP per year on housing.

Table 2: Household annual expenditure groups relative percentage in the studied sample, their average overall expenditure and their estimated expenditure on housing (Central Agency for Public Mobilization and Statistics, 2014)

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Relative % of families</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td>0.9</td>
<td>0.9</td>
<td>2.2</td>
<td>10.6</td>
<td>15.9</td>
<td>18.1</td>
<td>15.9</td>
<td>26.3</td>
<td>1.5</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Average annual HH expenditure</td>
<td>795.4</td>
<td>858.4</td>
<td>1,170.2</td>
<td>1,218.2</td>
<td>1,430.5</td>
<td>1,576.8</td>
<td>1,983.3</td>
<td>2,193.4</td>
<td>2,287.9</td>
<td>2,553.3</td>
<td>2,798.5</td>
<td>3,085.2</td>
<td>3,345.5</td>
<td>16,044.3</td>
<td>27,838.0</td>
<td>4,796.7</td>
<td>26,161.8</td>
<td></td>
</tr>
<tr>
<td>Average annual HH expenditure on housing</td>
<td>1,717.3</td>
<td>2,566.2</td>
<td>3,583.5</td>
<td>4,501.6</td>
<td>5,520.6</td>
<td>6,492.9</td>
<td>7,540.5</td>
<td>8,512.5</td>
<td>9,518.7</td>
<td>10,782.4</td>
<td>12,286.4</td>
<td>14,029.2</td>
<td>16,044.3</td>
<td>18,534.5</td>
<td>22,392.7</td>
<td>27,306.6</td>
<td>30,165.8</td>
<td></td>
</tr>
</tbody>
</table>

It’s concluded that there is a problem of housing affordability in Egypt. The research questions whether using different construction systems like ICF can improve housing affordability and help the government target poor families in housing projects and whether using ICF will affect a wide or a narrow negligible range of project beneficiaries.

**Affordable Housing Programs and Construction in Egypt**

Since the 1970s, the government has adopted a number of affordable housing programs to distribute the burden of construction among different role players: public sector, private sector and individuals. These programs included the provision of public housing, finished and unfinished units, sites and services housing, including core housing experiments after the peace treaty with Israel through the USAID, and public/private partnership housing (The World Bank, 2007). Finished housing units were the most popular, and are still delivered and adopted in future housing plans until 2020. The cost of the housing prototype is the most important factor affecting the design and construction of mass housing projects; any extra cost of a single unit will cause a huge increase to the whole housing program.

As a result in these projects, some principles of value engineering and cost minimization are commonly used with regards to area per unit, finishing materials, façade design, open spaces, urban amenities, density, site selection, and the choice of convenient construction systems. The latter is an important factor for housing economics but only few experiments were conducted to alter them, although the construction system constitutes around 40% of the cost of the housing project (Rageh, 2007).
Conventional Construction in Housing Projects in Egypt

For decades, housing projects have been constructed using skeletal structure of reinforced concrete slabs, and columns and beams with infill walls of fired clay bricks. Conventional methods are chosen because they are the most widespread and familiar for policy-makers, designers and builders. Over the years, the system has become a steady industry served by all kinds of investments, local materials, specialized labour, and building codes without any development.

Figure 2 Conventional Construction of recent mass housing projects in Egypt (Marc Angélil, 2016)

Due to the continuous shortage of affordable housing, conventional construction systems are a deep concern regarding their quality, speed and economic feasibility. There have been few experiments in Egypt where alternative building systems were used, yet those were unfortunately out-dated and didn’t fill the shortage (Al-Refai, 2010). Moreover, these experiments were individual initiatives led by heroic architects outside the realm of mass housing; they were not explored on a wider scale. Other unconventional systems like ICF have a proof-record of their feasibility over conventional construction in the building industry, however still to be adopted.

Non-conventional Housing Construction in Egypt

Non-conventional systems have been experimented in a limited number of affordable housing projects since the 1980s. These projects used tunnel forms, lift up slabs, load bearing walls, prefabricated reinforced concrete and sparlock blocks. The projects were developed at the new urban communities around the main cities such as New Salhiya, the nineteenth and twenty-ninth settlement in the 15th of May, Uthman Housing and Haram City (Al-Refai, 2010).

Some systems like prefabricated concrete and sparlock blocks achieved savings in construction costs. However, literature review of today’s trending sustainable construction systems proposes a wider spectrum of systems that can be used instead. Contemporary systems include ICF, structural insulated panels (SIP), structural composite insulated panels (SCIP), aerated concrete blocks, light gauge steel frame (LGSF), rammed earth and compressed stabilized earth blocks (CSEB). Except for SIP, all these systems are currently used in Egypt at a few numbers of projects. Some of these systems showed better quality and lower costs than conventional construction. This paper used ICF as a system for the simulation experiment in the selected case study, because ICF supports the construction of
multi-storey buildings unlike rammed earth and CSEB, which are limited to single and double-storey buildings. Moreover, ICF is cheaper than aerated concrete and LGSF.

**Insulated Concrete Forms as a Construction System**

ICF stands for Insulated Concrete Forms. It is a load bearing wall structure that consists of two layered panels of foam that act as formwork for concrete which is poured on site. The foam formwork is left in place and acts as a thermal barrier. The system is commonly used in the U.S.A and Europe, and started in Egypt in 2015. Egyptian developers of the system could get the Housing and Building Research Center’s approval on the system, and they constructed different project typologies like residential, commercial and educational buildings using ICF. The system is gaining popularity among building professionals in Egypt, due to the construction speed and quality, at a competent price compared to reinforced concrete and masonry conventional system.

ICF can either be used as load bearing or partitioning walls, but it is better to be used for load bearing because of its high strength and durability. On the other hand, lighter walls made of other materials like gypsum boards, foam core partitions and conventional brickwork are more competitive and economical to make partitions. The construction of ICF uses strip footing foundations, because ICF walls are heavy as they constitute mostly of reinforced concrete. ICF construction uses a variety of flooring options like cast in situ reinforced concrete, precast concrete, SIP floors, corrugated steel deck with concrete, foam core slabs, etc. In Egypt, after the construction some residential projects, it was found that the best flooring systems for medium rise residences are precast hollow core concrete slabs, post tension concrete slabs, and flat slab reinforced concrete. The choice of the flooring system is based on the projects location, site conditions, delivery deadline and allocated budget.

**ICF Performance**

ICF is a promising construction system that started to gain popularity among builders in Egypt recently because it achieves superior thermal and acoustic insulation quality, and a variety of finishing options. With spans of 11m, the system is nominated to be used for national mass housing projects as it is able to achieve good column-free flexible spans despite being a load bearing wall system.

The most important advantages of ICF construction are the high thermal resistance (9 times conventional construction), the high fire resistance (4 hours) (HBRC, 2015). Moreover,
ICF components are light and easy to handle, and doesn’t require highly skilled labour. The main drawbacks of ICF are that it is only a walls’ system; another system is used for slabs, and walls are relatively thick, as the thinnest load bearing wall is 27cm thick.

**Local ICF Industry**

ICF is rapidly growing in construction industry due to its competent cost and ease of construction. Currently there are two ICF factories in Egypt located in 6th of October and 10th of Ramadan cities producing collectively around 80,000 blocks per month. Material Take-off of the Social Housing project indicates that a single apartment building in the project uses around 5000 ICF blocks. This means that the production of these two factories can construct only 16 social housing buildings per month (288 units). Hence, current productivity amount of ICF is insufficient to bear a large portion of the planned mass housing due to the shortage of supply and further investments in the industry are needed. However, this is a growing industry that started in Egypt in late 2014, and proving its capabilities in a short period.

**Application of ICF on Current Social Housing Project in Egypt (2014-2020)**

This part examines the cost impact of ICF construction system on the current affordable housing project. The Ministry of Housing initiated “The Million Units Project” in 2012 as called by the media; it aims at constructing a million affordable units in a 5-year plan. In fiscal years 2012-2013 and 2013-2014, the government constructed 32,000 units and 48,000 consecutively, out of the estimated 200,000 units per year.

Due to insufficient construction rates in late 2014, the new minister of Housing Dr. Mostafa Madbouly, now appointed as Prime Minister as of June 2018, initiated a second edition of the Million Units Project with a more controlled time planning for construction and modified admission procedures. The aspired project is implemented using conventional construction systems of reinforced concrete beam, column and solid slab system with fired clay bricks infill for wall construction. The second edition of the million unit project seems more capable of meeting supply targets. The following table presents the breakdown of the number of units developed in the Social Housing Project each year until 2020. It is sorted through the implementing entities such as governorates, New Urban Communities Authority (NUCA) and private sector. It shows the number of units of different housing programs like ownership, self-construction, and rental programs (The World Bank, 2015).

<table>
<thead>
<tr>
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<td>50,000</td>
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<td>0</td>
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<td>Private Sector</td>
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<td>5,000</td>
<td>15,000</td>
<td>40,000</td>
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<td>Total</td>
<td>100,000</td>
<td>105,000</td>
<td>115,000</td>
<td>140,000</td>
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<td>30,000</td>
<td>75,000</td>
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<td>Low income rental</td>
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<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
<td>15,000</td>
<td>75,000</td>
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<tr>
<td>Private sector</td>
<td>0</td>
<td>0</td>
<td>5,000</td>
<td>10,000</td>
<td>15,000</td>
<td>20,000</td>
<td>50,000</td>
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<tr>
<td>Total low income units</td>
<td>100,000</td>
<td>120,000</td>
<td>135,000</td>
<td>185,000</td>
<td>215,000</td>
<td>245,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>
Every building consists of six floors with each floor consisting of four apartments summing up to 24 apartments per building. The built-up surface area of each floor is 360 square meters, and the gross area of each apartment is 90 square meters, while the net area is about 83 square meters. The apartment consists of three bedrooms, reception, kitchen, bathroom and balconies. The apartment is delivered fully finished. Buildings are attached to each other on both sides, with internal service courts created in between.

The project is constructed using conventional systems of reinforced concrete columns, beams and slabs with conventional fired bricks infill. Walls and related beams are of the same thicknesses either 12cm or 25cm while slabs thicknesses are 10cm. Floor height is designed at three meters, measured at finishing levels, with a clear height of 2.8m. Foundations are designed and constructed as isolated footing systems and columns are distributed as shown in the plan below.

The price of each apartment is 154K Egyptian Pounds with long-term instalments over twenty years. The down-payment to reserve an apartment is 9K Egyptian Pounds, and the rest is scheduled over seven to twenty years according to the financial and social status of the applicant with a minimum credit instalment of 350 pounds every month and the annual credit interest increase by 7%. Citizens eligible to apply for a residential unit must have a minimum monthly income of 1000 EGP, and a maximum monthly income of 2500 EGP for single applicants, and 3500 EGP for married couples and families. Concerning applicants who are not officially employed, running a small business, and craftsmen they are required
to present documents showing their income approved by a legal accountant, and their tax payments checks. According to the World Bank reports, the housing beneficiaries that are below the household poverty line are expected to reach 1.6 million individuals representing 37% of the total program’s beneficiaries.

The aforementioned income cap and regulations narrow the chances of low-income groups to continue paying instalments, creating an opportunity for the middle-income class to apply for the project. According to the financial data, an estimate of 75% of the Egyptian population are eligible to apply for the project as they satisfy the other application’s conditions (Central Agency for Public Mobilization and Statistics, 2014), meaning that most of the social housing project units will be directed to the middle-income class. Subsequently, most of the 500,000 units, entitled for social housing of the low income, may end for a whole different target-user because of its cost. Although the unit is much cheaper than the official market, the numbers show that many poor people will not be able to afford it, and the project will attract another segment of users.

**ICF Architectural Adaptation**

Considering replacing the conventional construction system of the social housing unit prototype with ICF, it needs strip footing under the load bearing walls to support the heavy weight of reinforced concrete walls. Moreover, it is necessary to decide on the thicknesses of walls. According to proposed designs by ICF practitioners, the walls consist of a 15cm concrete core, with two reinforcing steel bars 16mm² each, and 6cm of EPS (density 15Kg/m³) on both sides of concrete. The total thickness of walls is 27cm. Slabs are proposed to be 30cm thick hollow core slabs, or post tension slabs. However, hollow core is more convenient for mass housing and less time consuming than post tension slabs (Salaadin, 2017). Hollow core slabs can exceed 10m span, so the 8.10m span in the social housing project is not a problem in ICF. The ICF-prototype can be constructed without any internal columns are supporting load bearing walls inside the unit, as the ICF walls on the perimeter and hollow core slabs are enough. If hollow core slabs are used, it is important that the project planners consider the necessary cranes required for a certain number of units according to the time schedule and study their feasibility. Otherwise, other options like flat slab may be considered.

![Figure 6 Adapted prototype plan using ICF](image-url)
Cost and Time Estimates

According to the analysis and quantity survey for using ICF, a cost reduction of about 15% less than conventional construction can be achieved. This saving is expected to increase on large-scale mass housing projects because of the lump sum usage for both ICF and hollow core slabs construction. Although hollow core slabs are more expensive and use more concrete than the conventional 10cm solid slab used, however, hollow core slabs eliminate all beams, are more feasible for mass housing projects and reduce time on site, significantly. Construction time with ICF and hollow core system is 6 to 7 times quicker than conventional construction because they reduce slab construction time from 28 days to 4-5 days, additionally single post tension slabs are twice faster than conventional slabs as they reduce construction time of the slab to 14 days only.

In hindsight, ICF system is found to save around 15% of construction costs compared to conventional construction, which will have an impact on the residential unit cost. If the monthly payment of 350 EGP paid by the beneficiaries of the project is reduced by 15%, the new reduced payment of 300 EGP per month will be affordable by a lower economic segment assuming that each group spends 15-20% of their expenditure on housing as shown at the beginning. The new segment added to the project’s beneficiaries represents around 10% of the Egyptians, and 40% of the poor Egyptians. In other words, using ICF increases the beneficiaries of the project to include 80% of the poor segments of Egypt. The next table shows the impact of using unconventional ICF construction systems on the project beneficiaries of different expenditure groups.

### Table 4 Social Housing Project’s target expenditure group for different construction systems

<table>
<thead>
<tr>
<th>HH Expenditure Group</th>
<th>Relative % of families</th>
<th>Poor Families</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2999</td>
<td>0.0</td>
<td>4.8</td>
</tr>
<tr>
<td>3000-3999</td>
<td>0.0</td>
<td>5.9</td>
</tr>
<tr>
<td>4000-4999</td>
<td>0.3</td>
<td>10.6</td>
</tr>
<tr>
<td>5000-5999</td>
<td>0.3</td>
<td>18.1</td>
</tr>
<tr>
<td>6000-6999</td>
<td>0.5</td>
<td>15.9</td>
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<tr>
<td>7000-7999</td>
<td>0.6</td>
<td>26.3</td>
</tr>
<tr>
<td>8000-8999</td>
<td>0.9</td>
<td>7.0</td>
</tr>
<tr>
<td>9000-9999</td>
<td>0.9</td>
<td>1.5</td>
</tr>
<tr>
<td>10000-10999</td>
<td>2.2</td>
<td>1.5</td>
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<tr>
<td>11000-11999</td>
<td>2.6</td>
<td>100%</td>
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</table>

Concluding Remarks

The paper has discussed the problem of housing affordability in Egypt and investigated the effects of applying unconventional construction systems on the current Social Housing Project in Egypt. The use of different construction systems such as ICF has a significant impact on the architectural aspects of the project like choosing convenient wall thicknesses, load bearing elements, floor height, and design module. Concerning socioeconomic aspects resulting from the use of alternative construction systems it is found that using ICF construction can reduce construction costs about 15% which can increase affordable housing project beneficiaries with the same allocated budget.
References


Al-Refai, A. A.-R. (2010). The Effect of Building Technology on Solving the Problems of Housing, The Architectural Department, The Faculty of Engineering, Cairo University


Appendix

This is a comparison between the bill of quantities and cost estimation of conventional construction and ICF construction. Conventional construction specific tasks are highlighted in green, ICF specific tasks are highlighted in orange, and common tasks have no highlights. Electrical and plumbing works cost is roughly estimated according to their relative costs to structural and architectural works in similar projects. This approximate cost estimate relies on building materials prices data declared by the Central Agency for Public Mobilization and Statistics in May 2018. ICF blocks are priced according to Integral blocks firm’s prices in April 2018. These costs are notably higher than the original costs at the start of the project in 2014. The development of this cost study was reviewed by Integral blocks ICF manufacturer and Edarh contracting company for both ICF and conventional construction. All tasks are inclusive to all materials and labour costs.

<table>
<thead>
<tr>
<th>Num</th>
<th>Task</th>
<th>Quantity</th>
<th>Quantity (ICF)</th>
<th>Unit</th>
<th>Cost/Unit (EGP)</th>
<th>Conventional Cost (EGP)</th>
<th>ICF Cost (EGP)</th>
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<td>1</td>
<td>Digging and land fill</td>
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<td></td>
<td></td>
<td></td>
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<td>1/1</td>
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<td>1,030</td>
<td>m3</td>
<td>45</td>
<td>65,250.00</td>
<td>46,350.00</td>
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<td>½</td>
<td>Clean Sand site infill with compaction</td>
<td>750</td>
<td>650</td>
<td>m3</td>
<td>80</td>
<td>60,000.00</td>
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<tr>
<td>1/3</td>
<td>Sand Infill and compaction beneath structural elements</td>
<td>250</td>
<td>250</td>
<td>m3</td>
<td>40</td>
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<td>Plain concrete for foundations (Strength= 180 Kg/cm2)</td>
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<td>m3</td>
<td>1300</td>
<td>250,900.00</td>
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<td>Light plain concrete for roof slopes</td>
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<td>2/3</td>
<td>Plain concrete slab beneath ground floor level</td>
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<td>80</td>
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<td>3/1</td>
<td>Reinforced concrete for foundations (Minimum strength 250 Kg/cm2)</td>
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<td>m3</td>
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<td>629,000.00</td>
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<td>Reinforced concrete for foundations (Minimum strength 250 Kg/cm2) poured in ICF, no formwork needed</td>
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<td>Precast Hollow core slabs 30cm Thickness Strength 250 Kg/cm2</td>
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<td>Bitumen insulation paints for foundations</td>
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<td>680</td>
<td>m2</td>
<td>50</td>
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<td>Cement plaster of internal walls</td>
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<td>-</td>
<td>m2</td>
<td>65</td>
<td>253,500.00</td>
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<td>Internal ceilings plastering</td>
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<td>External ceilings plastering for balconies</td>
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<td>m2</td>
<td>60</td>
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<td>Façade cement plaster</td>
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<td>Façade finishing plaster including cornices</td>
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<td>3,000</td>
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<tr>
<td>Egyptian Galala marble tiles 40<em>40</em>2 cm for entrance lobby, corridors and stair landings</td>
<td>101</td>
<td>101</td>
<td>m2</td>
<td>250</td>
<td>25,250.00</td>
<td>25,250.00</td>
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<tr>
<td>4-2</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Ceramic tiles 30<em>30</em>0.8 cm for kitchen and bathroom floors</td>
<td>250</td>
<td>250</td>
<td>m2</td>
<td>100</td>
<td>25,000.00</td>
<td>25,000.00</td>
<td></td>
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<tr>
<td>4-3</td>
<td></td>
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<td></td>
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<tr>
<td>Ceramic tiles 40<em>40</em>0.8 cm for reception, rooms and corridors</td>
<td>1,620</td>
<td>1,620</td>
<td>m2</td>
<td>100</td>
<td>162,000.00</td>
<td>162,000.00</td>
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<tr>
<td>Cement tiles 20<em>20</em>2 cm for roof finishing</td>
<td>330</td>
<td>330</td>
<td>m2</td>
<td>70</td>
<td>23,100.00</td>
<td>23,100.00</td>
<td></td>
</tr>
<tr>
<td><strong>5</strong> Cladding works</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staircase Galala marble runs 120cm wide</td>
<td>130</td>
<td>122</td>
<td>Nu m</td>
<td>250</td>
<td>32,500.00</td>
<td>30,500.00</td>
<td></td>
</tr>
<tr>
<td>5-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staircase Galala marble runs 280cm wide</td>
<td>7</td>
<td>7</td>
<td>Nu m</td>
<td>600</td>
<td>4,200.00</td>
<td>4,200.00</td>
<td></td>
</tr>
<tr>
<td>5-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building entrance walls marble cladding 150cm high and 2cm thick</td>
<td>33</td>
<td>33</td>
<td>m2</td>
<td>500</td>
<td>16,250.00</td>
<td>16,500.00</td>
<td></td>
</tr>
<tr>
<td>5-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceramic tiles wall claddings 0.60 cm thick for kitchens and bathrooms</td>
<td>1,140</td>
<td>1,140</td>
<td>m2</td>
<td>120</td>
<td>136,800.00</td>
<td>136,800.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantity</td>
<td>Unit</td>
<td>Rate</td>
<td>Cost</td>
<td>Subtotal</td>
<td></td>
</tr>
<tr>
<td>---</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>Paints works</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-1</td>
<td>Internal walls paints</td>
<td>5,300</td>
<td>m2</td>
<td>40</td>
<td>212,000.00</td>
<td>212,000.00</td>
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</tr>
<tr>
<td>6-2</td>
<td>Ceilings paints</td>
<td>360</td>
<td>m3</td>
<td>35</td>
<td>12,600.00</td>
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<td>7</td>
<td>Carpenter works</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-1</td>
<td>Natural wood door 100 cm wide</td>
<td>24</td>
<td>Num</td>
<td>2000</td>
<td>48,000.00</td>
<td>48,000.00</td>
<td></td>
</tr>
<tr>
<td>7-2</td>
<td>Natural wood door 90 cm wide</td>
<td>72</td>
<td>Num</td>
<td>2000</td>
<td>144,000.00</td>
<td>144,000.00</td>
<td></td>
</tr>
<tr>
<td>7-3</td>
<td>Natural wood door 80 cm wide</td>
<td>48</td>
<td>Num</td>
<td>1800</td>
<td>86,400.00</td>
<td>86,400.00</td>
<td></td>
</tr>
<tr>
<td>7-4</td>
<td>Wooden window with louvers 120 *120 cm</td>
<td>72</td>
<td>Num</td>
<td>1800</td>
<td>129,600.00</td>
<td>129,600.00</td>
<td></td>
</tr>
<tr>
<td>7-5</td>
<td>Balcony wooden doors with louvers 120 cm wide</td>
<td>24</td>
<td>Num</td>
<td>1800</td>
<td>43,200.00</td>
<td>43,200.00</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Aluminium works</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-1</td>
<td>Aluminium windows 60 * 70 cm for kitchens and bathrooms</td>
<td>48</td>
<td>Num</td>
<td>2000</td>
<td>96,000.00</td>
<td>96,000.00</td>
<td></td>
</tr>
<tr>
<td>8-2</td>
<td>Aluminium doors 80 cm wide for laundry sunroom</td>
<td>24</td>
<td>Num</td>
<td>2000</td>
<td>48,000.00</td>
<td>48,000.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total structural and architectural works</td>
<td></td>
<td></td>
<td></td>
<td>6,029,675.00</td>
<td>5,044,430.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total plumbing works</td>
<td></td>
<td></td>
<td></td>
<td>250,000.00</td>
<td>250,000.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total electrical works</td>
<td></td>
<td></td>
<td></td>
<td>700,000.00</td>
<td>700,000.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total cost of an apartment building of 24 apartments</td>
<td></td>
<td></td>
<td></td>
<td>6,979,675.00</td>
<td>5,994,430.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall estimated apartment’s cost (EGP)</td>
<td></td>
<td></td>
<td></td>
<td>290,819.79</td>
<td>249,767.92</td>
<td></td>
</tr>
</tbody>
</table>
How sensitive are whole-buildings life cycle assessment to lifespan choices?

Gabriela Dias Guimarães¹, Arthur Gusson Baiochi¹, Marcella Ruschi Mendes Saade¹, Vanessa Gomes da Silva¹

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Abstract: Life cycle assessment (LCA) is an important technique to measure environmental impacts of products and processes. Its application to analyze whole-buildings’ environmental burdens has increased in the past years. Its results, however, carry uncertainties which may impair LCA’s assistance to environmental decision-making. Since choices are unavoidable in LCAs, it is crucial to analyze inherent uncertainties. Recent papers indicate lifespan as one of the main uncertainty drivers on whole-building LCAs, since future situations can not be assertively predicted. Literature also suggests that increasing a building’s reference service life (RSL) offers improved performance, as described terms of impact per year of RSL. This outcome however has been observed in highly industrialized and standardized construction contexts. Less controlled contexts, characterized by waste- and maintenance-intensive technologies, might not follow the same trend. This study assesses sensitivity of whole-building LCAs results to different lifespans illustrated by a Brazilian case study. Our chosen lifespan scenarios (50, 75 and 100 years) were inspired by the three design service life compliance levels admitted by the Brazilian performance standard. We then performed a sensitivity analysis to clarify the implications of longer building’s lifespan on other life-cycle phases, particularly maintenance. Cumulative Energy Demand (CED) and CML 2001 v.2.05 methods were selected for calculating embodied energy and global warming potential in SimaPro 7.3. Our results indicate that wastage inherent to building technologies, as well as use of poor quality materials indeed intensify maintenance routines, however it is not enough to make the annualized impact less attractive for longer lifespans. The sensitivity analysis indicates materials and services with higher repair program impacts and problematic impact categories. Findings from this research will support future sensitivity analysis in whole-building LCAs.

Keywords: Life cycle assessment; whole-buildings; lifespan; sensitivity analysis

Introduction

The built environment represents one of the biggest paradoxes of modern life: while it is considered a great encourager of global socioeconomic development, with high job creation rates and large representation of countries’ GDP, it is also responsible for innumerous environmental impacts, given its strong need for natural resources and pollution emissions. Globally, buildings’ construction and operation are the largest greenhouse gas emitters and, due to the high number of materials involved, require an enormous amount of raw material supply (Haefliger et al., 2016), with equally important end-of-life waste mass. All these facts make a clear case for environmental impacts evaluation. Life Cycle Assessment (LCA) is already a common technique to quantify such effects, able to cope with the constructive complexity, whilst bringing a holistic approach to the analysis (Khasreen, Banfill and Menzies, 2009).

Despite its increased use, LCA results are highly doubtful (Pomponi, D’Amico and Moncaster, 2017). The number of input parameters required, lack of adequate database, different methodological choices available, use of simplistic models and the assumptions required weaken the results quality. In addition, deterministic outcomes fails to capture the inherent variability and uncertainty, giving a false sense of certainty to the assessment (Lloyd and Ries, 2007).
LCA at whole-building level (WBLCA) adds considerable complexity, due to particular characteristics within the construction steps, demonstrated on Figure 1. Since an LCA aggregates all environmental interactions throughout the life cycle stages, adding up all materials and processes involved, inherent uncertainties in whole-building assessments are higher than usual.

<table>
<thead>
<tr>
<th>A1-3</th>
<th>A4-5</th>
<th>B1-7</th>
<th>C1-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT stage</td>
<td>CONSTRUCTION PROCESS stage</td>
<td>USE stage</td>
<td>END OF LIFE stage</td>
</tr>
<tr>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
</tr>
<tr>
<td>Raw material supply</td>
<td>Transport</td>
<td>Manufacturing</td>
<td>Construction-installation process</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits and loads beyond the system boundary</td>
</tr>
<tr>
<td>Reuse-Recovery-Reycling</td>
</tr>
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</table>

Figure 1 - Building life cycle information. Source: EN15978 (2011)

Uncertainties on LCA results are driven by different reasons, and commonly categorized into parameter, scenario and model uncertainty (Huijbregts et al., 2003). Parameter uncertainty represents total or partial data inaccuracy; scenario uncertainty relates to intrinsic normative choices in an LCA, and model uncertainty results from aspects simplifications that cannot be modeled within an LCA framework (Huijbregts, 1998).

Within the scenario category, an important uncertainty source in WBLCA is the building’s long lifespan (Sandin, Peters and Svanström, 2014), since future situations cannot be assertively predicted. Furthermore, LCA results are distributed through the number of years adopted as reference (building) service life, naturally long-lasting materials will appear worse on shorter periods than on expanded ones. Longer lifespans also implies in additional replacements and possible chances in the construction technique, which will add corresponding environmental impacts (Birgisdóttir and Rasmussen, 2016).

WBLCA studies frequently use typical and definite values to represent temporal horizon (Hasik et al., 2017). However, this tactic does not realistically evaluate the environmental impacts. Several building materials are replaced or undergo maintenance during a building’s life cycle, at a frequency which affect the total amount of material extraction and waste generation over the period of study (Haefliger et al., 2016). Lifespans are also susceptible to occupant behavior, construction technology, regulatory policies, future trends and other aspects.

In addition to the difficulties in predicting replacements within the complete life cycle, an average building suffers different changes of form and function, which can be as significant as the original product (Khasreen, Banfill and Menzies, 2009). Moreover, some materials change their impact magnitude throughout the life cycle: for example, the toxicity of certain materials may differ by up to six orders of magnitude (Huijbregts et al., 2003). Hence, inclusion of accurate lifetime information supports improved assessment outcomes (Aktas
and Bilec, 2012). Such accuracy is however under - long - ongoing discussion within the technical community in most countries.

Another approach is to carry out sensitivity analysis to understand how results would change with varied service life scenarios. Though the probability of different lifespan scenarios is undertaken in some publications (Souza et al., 2016; Häfliger et al., 2017), its influence on results is seldom analysed.

Although the Brazilian performance standard suggests 50 years as the reference period for structural systems (NBR 15575:2013), some authors suggest and have investigated if increasing a building's service life would offer improved performance, as described terms of impact per year. This hypothesis was verified in highly industrialized and standardized construction contexts. Less controlled contexts, characterized by waste- and maintenance-intensive technologies, might not follow the same trend.

To help to fill in this research gap, this study assesses sensitivity of WBLCA results to different lifespan choices, illustrated by two life-cycle indicators - embodied energy and GHG emissions – calculated for a case study.

Method

This article was developed in four steps: (i) lifespan scenario planning and detailed description of a case study’s materiality; (ii) calculation of life-cycle embodied energy and GHG emissions; (iii) sensitivity analysis; and (iv) results analysis and discussion.

Our case study (Figure 2 and Figure 3) is the ‘Urban and Rural Educational Space’ standardized design developed by the Brazilian National Education Development Fund (FNDE) to attend up to 360 students (in two shifts) in six classrooms countrywide. The design is based on conventional building techniques: reinforced concrete structure, plastered 8-hole ceramic brick façade and partitions, and clay roof tiles over wooden structure.

Figure 2 - Case study is a six-classroom standard school building design
(image source: http://www.fnde.gov.br/programas/par/eixos-de-atuacao/infraestrutura-fisica-escolar/item/5956-projeto-espa%C3%A7o-educativo-urbano-e-rural-6-salas)
The LCA was developed in accordance with ISO 14040 (ISO, 2006). Table 1 summarizes the methodological choices made throughout the evaluation. Even though using a single database is theoretically recommended for consistency sake, it results unfeasible in practice, and some parameters were taken from literature. The end-of-life phase only considers steps C1-C2.

### OBJECTIVE

<table>
<thead>
<tr>
<th>WBLCA Sensitivity to RSL choice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope</strong></td>
</tr>
<tr>
<td><strong>Reference service life (RSL) scenarios</strong></td>
</tr>
<tr>
<td><strong>Fuctional unit</strong></td>
</tr>
<tr>
<td><strong>Inventory data</strong></td>
</tr>
<tr>
<td><strong>Impact assessment methods</strong></td>
</tr>
<tr>
<td><strong>Impact categories</strong></td>
</tr>
</tbody>
</table>

Table 1 - LCA information summary. Source: The authors

To understand how WBLCA results are influenced by lifetime choices, we used ‘scenario analysis’, a sensitivity analysis whose procedure includes estimation of the effects that parameters and input choices produce on final results by describing possible future situations (Björklund, 2002). Our chosen lifespan scenarios (50, 75 and 100 years of RSL) were inspired respectively by the minimum and maximum design service life compliance levels prescribed by the Brazilian performance standard (NBR 15575:2013), and by the international trend of offering buildings with elongated service life. This scenario planning format is aligned with the ideal design suggested by Wack (1985), composed of a base scenario and two alternatives focusing on critical uncertainties.

The reinforced concrete structure was remodelled to meet the stipulated scenarios which defined the building reference service lives. Maintenance replacement routines for the remaining building components/systems were redefined accordingly. Service life adjustment was supported by Life-365 v.2.2.3 software (EHLEN, 2018). The software considers different
strategies for service life increase, by using (1) maintenance and repair programs; (2) chemical corrosion inhibitors; (3) increased concrete cover; (4) sealers or membranes; (5) stainless steel rebars; and (6) silica fume as mineral admixture. To represent Brazilian typical practice and the Brazilian standard NBR 15575-1 (2013) recommendation that stipulates that systematic preventive maintenance should be planned and carried out whenever needed, in this paper we opted for maintenance and repair interventions to ensure service lives that matched the preset lifespan scenarios. The assumed maintenance program consists on repair events held every 10 years, consisting on a 10%-material addition (OLIVEIRA, 2013).

Life-365 v.2.2.3 software divides service life into initiation and propagation stages. Initiation refers to the time needed for chlorides to reach steel rebars. Propagation depends on the corrosion process rate and defined unacceptable damage level (EHLEN, 2018). Table 2 shows characteristics and corresponding service life outputs for the different structural elements considered.

<table>
<thead>
<tr>
<th>Structural elements</th>
<th>Thickness (mm)</th>
<th>Reinforcement Depth (mm)*</th>
<th>Area (m²)</th>
<th>Mixture w/cm</th>
<th>Slag (%)</th>
<th>Service life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slabs</td>
<td>150</td>
<td>35</td>
<td>127,28</td>
<td>0,5</td>
<td>30</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structural elements</th>
<th>Width (mm)</th>
<th>Reinforcement Depth (mm)*</th>
<th>Length (m)</th>
<th>Mixture w/cm</th>
<th>Slag (%)</th>
<th>Service life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns</td>
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<td>2,1</td>
<td>0,5</td>
<td>30</td>
<td>14,2</td>
</tr>
<tr>
<td>Beams</td>
<td>400</td>
<td>40</td>
<td>1</td>
<td>0,5</td>
<td>30</td>
<td>14,2</td>
</tr>
</tbody>
</table>

Table 2 - Software input/output data for the different structural elements considered. Source: The authors

Results

The quantified services in the life cycle assessment were divided into: preliminary services, soil excavation/movement, foundation construction, superstructure, frames, internal partition walls, structural frame roofing system, waterproofing membrane/treatment, interior and exterior wall and floor finishing; building services (water, gas, wastewater/sewage, fire protection, electricity, atmospheric discharge protection, and telecom), sanitary ware and metals, complementary and final services.

Table 3 summarizes the LCA outcome for each lifespan scenario in terms of total impacts and maintenance, whilst all remaining phases were kept unaltered. The growth in each impact category was expected, since longer lifespans result in increased material input, repair incidence and corresponding emissions throughout the building’s life cycle. To properly analyze the implications of the different scenarios, it is necessary to conduct a sensitivity analysis.

<table>
<thead>
<tr>
<th>Life cycle impacts</th>
<th>Module - B2 of Use stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EE [GJ]</td>
</tr>
<tr>
<td>50 years</td>
<td>6918,33</td>
</tr>
<tr>
<td>75 years</td>
<td>8667,59</td>
</tr>
<tr>
<td>100 years</td>
<td>9996,63</td>
</tr>
</tbody>
</table>

Table 3 - LCA results (total analysis and maintenance phase). Source: The authors
When RSL is increased by 100% (from 50 to 100 years), maintenance-to-lifecycle embodied impact ratios increase only by 13% for both EE $N_{\text{REN}}$ and GWP, as shown in Figure 4. This confirms the suggestions in literature that buildings with longer lifespans are achievable at low embodied impact increase.

![Figure 4](image)

Figure 4 – Maintenance-to-lifecycle embodied impacts ratios for the three reference service life (RSL) scenarios considered. Source: The authors

Even though EE $N_{\text{REN}}$ and GWP show similar trendlines, the increase is not linear, and values slightly decrease in the second interval (75 to 100 years). Such outcome does not result simply from structural repair, but also from the varied contributions from each service maintenance interventions, as shown in Figure 5 and Figure 6.

Superstructure has the biggest contribution to embodied energy, due to the well-known high environmental impact of cement production and to the maintenance program stipulated for structural elements, which adds extra cement-based material in regular intervals. Window frames, roof structure, walls, floor finishing and wastewater installation were the other relevant contributors to this category.
As to greenhouse gas emissions, window frames are the main contributors. Aluminum frames represent more than half of the total “frame” system impact, regardless of the chosen RSL. This is mainly due to primary aluminum production, which responds for 1% of global anthropic GHG emissions (IAI, 2003). In Brazil, primary aluminum production represents up to 90% of this industry’s CO$_2$ emissions (ABAL, 2012), and most aluminum-based products already incorporate over 60% of secondary material. Still, aluminium plays a critical role in the overall impact. Floor finishing, walls, wastewater installation and painting were the other lead contributors.
Figure 6 - Contributors to greenhouse gas (GHG) emissions in maintenance interventions. Source: The authors

Despite the increased maintenance impacts necessary for longer building’s service life, the annualized impacts decrease considerably for GWP (~32%) and embodied energy (~28%) (Figure 7).

Figure 7 – Annualized lifecycle embodied impacts, for the RSL scenarios considered. Source: The authors
Conclusions

The adopted reference service life fundamentally influences LCA results, as it affects material quantities, maintenance programs, and corresponding emissions and waste through a building’s life cycle. Understanding the proper impact of longer lifespans in a specific reality demands comparative analysis of scenarios outcomes.

This study assesses the sensitivity of whole-building LCAs results to the lifespan scenarios considered. Our results confirmed that increased lifespans are attractive - as the impact per additional year of service life is considerably reduced over time - even though the selected option (maintenance programs) implies in added material and corresponding impacts.

Lastly, we highlight two fronts to be further investigated. Since this added impact per year is different for each material and repair program, other alternatives supported by Life365 v.2.2.3 software could result in different contributions or even offer an optimal solution from the environmental viewpoint. Also, in this paper our calculations were illustrated for greenhouse gas emissions and embodied energy only. It is known that other impact categories, such as acidification and eutrophication potential, may be also relevant for specific building materials or in specific contexts. Both aspects are targeted in ongoing investigations.

References


Development of tools for the proper prediction of urban cooling potential associated with the implementation of cool and green roofs. Application to a case study

Abstract: In Mendoza city, Argentina, the intensive sealing of surfaces, due to urban growth, increases the temperatures of the outdoor air and the surfaces of the urban-building envelope. Mitigation strategies aim to restore the thermal balance of cities, favouring losses and decreasing profits. Internationally, one of the most efficient strategies is the application of cool and green roofs. The objective of the investigation is to generate reliable predictive tools that describe the microclimatic changes derived from the use of cool and green roofs, developed and used locally, over urban environments of arid regions. Methodologically, three stages were carried out: (1) Experimental test: evaluation of the thermal and optical performance of cool roofing materials of greater local application -aluminium and geotextile membranes- and vegetated roofs with greater hygrothermal efficiency in the region with the species Nassella tenuissima and Sedum spectabile. (2) Databases: generation of input data of materials and technologies of roof for urban climate forecasting software, ENVI-met, adjusted to the regional technology features through their optical and thermal characterization. (3) ENVI-met theoretical models: comparison of the thermal behaviour of 4 scenarios that differ in their cover technology with respect to a base case. As a result, the high degree of adjustment of the air temperature of the daily curves measured in comparison with the simulated curves is observed, which supports the reliability of the predictive results of ENVI-met in relation to the urban thermal behaviour. As a final conclusion, the combination of variables, such as the selection of plant species used in green roofs in relation to the local climate resources and diverse roofing technologies, would allow for different energy efficiency measurements at object, building and urban scale. The adjustment of prediction tools through simulation that links models at different scales, such as Energy Plus and ENVI-met, would improve both sustainable buildings design and urban planning.

Keywords: urban passive cooling, roof technologies, green roofs, cool roofs, arid zones.

Introduction

The growth of cities increases the outdoor air and surface temperatures of the urban-building envelope contributing to an urban warming effect. This phenomenon exacerbates the energy consumption of buildings and increases air pollution, as well as reducing decreasing indoor and outdoor thermal comfort and the health condition of the population, especially the most economically vulnerable (Santamouris and Kolokotsa, 2015).

In order to counteract the increase in temperature in the urban environment, and to minimize its impact on energy consumption and the environment, mitigation technologies have been developed and widely applied (Akbari et al., 2016). Such mitigation technologies include the use of reflective materials for solar radiation, and urban greening (Akbari and Kolokotsa, 2016).

The roof areas are suitable surfaces to apply these technologies, since they present a very high fraction of exposure to the sky, added to the fact that the available area of free land in an urban environment is quite limited and of very high economic value (Akbari and Rose, 2008).
Cool and green roofs can reduce surface temperature, and both the sensitive heat flow delivered to the atmosphere and into non-isolated buildings (Zinzi and Agnoli, 2012). Moreover, regarding indoor behaviour, an uninsulated green roof can help cool a space in two ways: The canopy layer reduces the effect of solar gains by reducing the sol-air temperature, and the growth medium acts as a heat sink. In hot and dry climates, it has been documented that the uninsulated green roof exhibits greater performance than the insulated green and white roofs. Furthermore, the vegetation in the canopy layer perfects/improves/meliorates the system by blocking solar gains (La Roche P., 2009).

Regarding as cool roofs, it has been shown that increasing the reflectivity of roofs is an efficient, inexpensive, and easy to implement cooling strategy. Initially, the concept of cool roofs was restricted only to white surfaces that exploit their intrinsic property of reflecting light in the range of the solar spectrum. In recent years, highly reflective coloured materials have been developed. Sheets, membranes and light reflecting paint and coating have been made with pigments that increase reflectance in the near infrared.

On a different line of research, Solcerova et al. in 2017 showed that under well-watered conditions, the air above the green roof, compared to the white gravel roof, was colder at night and warmer during the day. This suggests that extensive sedum-covered green roofs might help decrease air temperatures at night, but possibly contribute to high daytime temperatures. These results show the importance of conducting tests with different types of cool and green roofs in buildings considering the particular local climate.

The hypothesis of this project suggests that green technologies and the materials of the building envelopes contribute to the sustainability of the built environment when their development and implementation respond to efficiency criteria, from the energetic and environmental point of view, set in accordance to the available natural resources, technology features, and development models of each city. In this context, the data generation from the optical and thermal characterisation of local technology; will improve the performance of predictive tools for the adequate selection of technologies in terms of energy consumption reduction and environmental behaviour enhancement.

The objective of this research to create thermal and optic properties databases (inputs) of roofing technologies adjusted to the regional reality, which in turn might be applicable to energy efficiency calculation models. This knowledge may enhance the prediction of thermal behaviour, the accuracy of energy losses and gains of a building and the description of the microclimatic changes of urban environments in an arid context.

**Materials and methods**

In order to achieve this objective, experimental analysis of different green roofs and roofs covered by membranes was be carried out, as well as the study of the thermal behaviour of buildings and urban environments by means of Energy Plus and ENVI-met software.

Methodologically this research project was structured in three stages: 1) Experimental test: assessment of the thermal and optic behaviour of four roofing technologies - two vegetated roofs and two cold roofing materials of greater local use; (2) Databases: generation of input data of materials and technologies of roof coming from the properties measured in the stage one and the thermophysical characteristics of the green roof with each plant species adjusted by mean of software ENERGY PLUS; (3) ENVI-met theoretical models: comparison of the external thermal behaviour of 4 urban scenarios that modify their materials and technologies in an urban area of Mendoza, Argentina.
In order to test the thermal performance of the cool and green technologies according to their optical (solar reflectance and emissivity) and thermal properties; two roof materials of greater local application were evaluated, aluminum and geotextile membranes; and two green technologies with greater hygro-thermal efficiency in the region- composed by: *Nassella tenuissima* and *Sedum spectabile* species. The optic and thermal behaviors of roofs were studied during the summer seasons of 2018. The materials were placed over 10 cm of high density expanded polystyrene in the Regional Center of Scientific and Technical Research, in the west area of the city (N: 32º53’N; 68º51’W).

**Instrumentation**

The meteorological conditions during the days studied were recorded with ONSET Weather, HOBO® type and H21-001 model (operating range between 253 and 323 K). The weather station is made up by: HOBO S -THB - M002 61 temperature and relative humidity sensor, HOBO S-WSA-M003 wind speed sensor, HOBO S-WDA-M003 wind direction sensor, HOBO S LIB-M003 silicon pyranometer and HOBO S-GAP-CM10 barometric pressure sensor.

To characterise the thermal and optic behaviour of roof technologies and roof membranes, the following instrumentation and methods were used:

- Solar reflectivity (\(\alpha\)), a CM3 Kipp & Zonen albedometer was used along with a pair of white and black masks over the 1 m\(^2\) area surface, in conjunction with the method developed by Akbari et al., 2008.
- Emissivity (\(\varepsilon\)), was obtained according to regulation ASTM E1933-99a, 2006 through a temperature sensor with a type T thermocouple associated with data logger hobbo U12.
- Surface temperature (\(T_s\)), was registered by an IR Fluke Ti 55 camera, which detects infrared long wave radiation on a range of 7.5 to 14 \(\mu\)m within the electromagnetic spectrum. The surface temperatures were contrasted with type T thermocouples incorporated to a data logger LASCAL EL-USB-TC. (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Environmental characteristics of the monitored days</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Membrane monitoring day (February 7, 2018)</strong></td>
</tr>
<tr>
<td>Unit</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
</tbody>
</table>

<p>| <strong>Averages of the monitoring period of green roofs (March 2-5, 2018)</strong> |
|--------------------------|-------------------------|----------|-------|-------------------|</p>
<table>
<thead>
<tr>
<th>Unit</th>
<th>Solar radiation, W / m(^2)</th>
<th>Temp, °C</th>
<th>RH, %</th>
<th>Wind speed, m / s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>267.22</td>
<td>25.0</td>
<td>43.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>914.10</td>
<td>35.3</td>
<td>49.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Minimum</td>
<td>/</td>
<td>20.7</td>
<td>39.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Thermal and optical behavior**

Figure 1 describes the thermal and optical characteristics of roofing materials and technologies during the monitored period. The behaviour of the membranes corresponds to 13 hours on 7 February, 2018 and the behaviours of green roofs correspond to the averages of 2 to 5 March, 2018.
The albedo of the membranes is higher than vegetated roofs; the aluminum membrane shows the highest value -86%-. The white geotextile membrane presents albedo 10% lesser than of aluminum membrane. The green roofs have low and similar values of albedo -46% for Sedum sp. and 47% Nassella sp.-. The average surface temperature is similar between the white geotextile membrane and the Nassella sp. green roofs, approximately 41 °C. In contrast, the roof with Sedum sp., shows an average surface temperature of 44 °C and the aluminum membrane has the highest surface temperature - 47 °C-. Observing these results, it is evident that the most efficient roofing material to reduce urban temperatures is the white membrane.

1- Databases

Simulations in Energy Plus software were run to determine the thermophysical characteristics of the green roof built with both of the evaluated plant species (Nassella sp. and Sedum sp.)

**Dynamic simulations with Energy Plus: model definition and validation**

To assess the thermal behaviour of green roofs, experimental tests were carried out by monitoring three boxes with different green roof technologies, during summer for two years. The methodology details are described by Flores Asin, et al (2016).

The measurements data taken were contrasted with those obtained by dynamic simulations. To develop the simulations, the boxes were geometrically defined using Open Studio Plug-in program for SketchUp Pro Version 2016, from which, the data was entered into the Energy Plus software version 8.8 (Energy Plus, 2009).

The adjustment of the simulation model had two stages: at first, the control case was simulated. Thermal and optical properties of building materials of boxes were obtained according to local bibliography (Esteves, 2017). In the roof a layer corresponding to reinforced concrete was input at simulator. Walls were input as an item composed of three layers (from interior to exterior): a chipboard plate, expanded polystyrene and a cement board plate. The same layers were used in the floor, plus a layer of concrete (subfloor) and soil. In a second stage the “Material Roof Vegetation” module was added.
A description of the construction data assumed in the model is presented in Table 2 for the control case and for green roof module in Table 3.

### Table 2. Detailed construction data of the control case

<table>
<thead>
<tr>
<th>Layers</th>
<th>Roughness</th>
<th>Thickness [m]</th>
<th>Conductivity [W/m°C]</th>
<th>Density [Kg/m³]</th>
<th>Specific Heat [J/Kg°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOF</td>
<td>Rough</td>
<td>0.15</td>
<td>1.7</td>
<td>2400</td>
<td>800</td>
</tr>
<tr>
<td>Reinforced Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WALLS</td>
<td>Medium smooth</td>
<td>0.018</td>
<td>0.17</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Chipboard</td>
<td>Medium smooth</td>
<td>0.03</td>
<td>0.04</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Expanded polystyrene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement board</td>
<td>Medium smooth</td>
<td>0.01</td>
<td>0.15</td>
<td>600</td>
<td>800</td>
</tr>
<tr>
<td>FLOOR</td>
<td>Rough</td>
<td>1.00</td>
<td>0.87</td>
<td>2000</td>
<td>840</td>
</tr>
<tr>
<td>Soil</td>
<td>Rough</td>
<td>0.05</td>
<td>0.78</td>
<td>1600</td>
<td>780</td>
</tr>
<tr>
<td>Concrete (Subfloor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chipboard</td>
<td>Medium smooth</td>
<td>0.018</td>
<td>0.17</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Expanded polystyrene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement board</td>
<td>Medium smooth</td>
<td>0.01</td>
<td>0.15</td>
<td>600</td>
<td>800</td>
</tr>
</tbody>
</table>

### Table 3. Detailed data entered for “Material: Roof Vegetation”

<table>
<thead>
<tr>
<th>Field</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of Plants</td>
<td>m</td>
<td>0.46</td>
</tr>
<tr>
<td>Leaf Area Index</td>
<td>dimensionless</td>
<td>1.5</td>
</tr>
<tr>
<td>Leaf Reflectivity</td>
<td>dimensionless</td>
<td>0.35</td>
</tr>
<tr>
<td>Leaf Emissivity</td>
<td>dimensionless</td>
<td>0.95</td>
</tr>
<tr>
<td>Minimum Stomatal Resistance</td>
<td>s/m</td>
<td>50</td>
</tr>
<tr>
<td>Soil Layer Name</td>
<td></td>
<td>Green roof soil</td>
</tr>
<tr>
<td>Roughness</td>
<td></td>
<td>Very rough</td>
</tr>
<tr>
<td>Thickness</td>
<td>m</td>
<td>0.12</td>
</tr>
<tr>
<td>Conductivity of Dry Soil</td>
<td>W/m K</td>
<td>0.20</td>
</tr>
<tr>
<td>Density of Dry Soil</td>
<td>kg/m³</td>
<td>1800</td>
</tr>
<tr>
<td>Specific Heat of Dry Soil</td>
<td>J/kg K</td>
<td>1600</td>
</tr>
<tr>
<td>Thermal Absortance</td>
<td></td>
<td>0.90</td>
</tr>
<tr>
<td>Solar Absortance</td>
<td></td>
<td>0.54</td>
</tr>
<tr>
<td>Visible Absortance</td>
<td></td>
<td>0.75</td>
</tr>
<tr>
<td>Saturation Volumetric Moisture Content of the Solid Layer</td>
<td></td>
<td>0.24</td>
</tr>
<tr>
<td>Residual Volumetric Moisture Content of the Solid Layer</td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>Initial Volumetric Moisture Content of the Solid Layer</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>Moisture Diffusion Calculation Method</td>
<td></td>
<td>Advanced</td>
</tr>
</tbody>
</table>
Other aspects considered for the adjustment were:

- The Heat Balance Algorithm used in this model was Conduction Transfer Functions.
- The convective coefficients of the surfaces for the interior walls, floor and roof were set at 6 W/m²K (Duffie and Beckman, 1991). Convective coefficients of the exterior walls are calculated by the software through a detailed model that processes surface orientation, wind speed and direction.

The box was adjusted in a period of 10 days, from 9 to 18 January. Simulations were programmed for one month before the selected date because it is important that the physical model is entered in advance.

Figure 2 shows the relationship of measured and simulated temperatures in the two cases studied: the control case and the green roof vegetation (R²_Simulation control case=0.98; R²_Simulation green roof with Nassella tenuissima=0.73; R²_Simulation green roof with Sedum spectabile=0.77). The simulated model for the control case are set up for minor differences of 1 °C when compared to the measured data, except in the maximum, where the simulated temperatures are 2 °C less than the measures. For the case with the roof vegetation module it can be observed time differences between the simulated model and the measured one: the simulated case presents a greater gain (two hours) with respect to the measured case.

Figure 2. The relationship of measured and simulated temperatures

2- ENVI-met theoretical models

Four scenarios were designed and compared with a base case in order to quantify the impact of changing the building roof technology over urban microclimatic conditions. These scenarios were simulated by ENVI-met software. The input data referred to roof technologies were taken from the stages one and two.

Description of study area

For this research, a social neighborhood of Mendoza Metropolitan Area (MMA), called Barrio Cementista, was selected as study case. The evaluated area features correspond to low building density and residential use. Regarding the morphological configuration, the area is characterised by rectangular blocks, between 16 and 20 m street width, 3 m sidewalk.
width, 3 m building height, 0.15 to 0.19 relationship between building height and street width (H/W), 80% of average built-up area in batches and 13% of urban forestation mainly white Morus alba (Sosa et. al, 2017).

The average solar reflectance (â) of vertical materials is 0.25. In horizontal surfaces, the streets are made of concrete pavement and the roofs are predominantly sloped with ceramic tiles (â = 0.35) (Alchapar et al., 2016). Widespread use of pedestrian calcareous type pavement, in red colors (â = 0.3). This pavement group represents 80% of all the sidewalks in MMA (Alchapar et al., 2014).

Support tool. ENVI-met software

For the dynamic assessment of microclimate at the urban scale, the ENVI-met 3.1 software was used, which was developed by Bruse (1999) in Bochum University, Germany and it is continuously updated. More details on the software and its intrinsic laws are available at www.envi-met.com.

This tool is extensively validated worldwide. Several studies evaluated ENVI-met potential to predict the effects on urban microclimate and outdoor thermal comfort, when vegetation, urban morphology, materials, and atmospheric conditions are modified (Yang, et al., 2012; Yuan, et. al, 2017).

15 January, 2014 was selected as the reference date. This day is a typical summer day in Mendoza (39.0 ºC maximum temperature, 21.0 ºC minimum temperature, 30.0 ºC average temperature and 25 % average relative humidity). Table 4 shows the instrumentation used for monitoring the base case in the observed point (Op).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Instruments</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>HOBO® H08-003-02</td>
<td>±0.7 ºC to + 21 ºC</td>
</tr>
<tr>
<td>Humidity relative</td>
<td>HOBO® H08-003-03</td>
<td>5%</td>
</tr>
<tr>
<td>Wind velocity and direction</td>
<td>HOBO S-WSA-M003</td>
<td>±1.1 m/s or 4 % of reading (the highest value).</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Silicon Pyranometer smart sensor S-LIB-M003</td>
<td>±10 W/m² or ±5 % whichever is greater in sunlight additional temperature-induced error ±0.38 W/m²/°C from 25 ºC.</td>
</tr>
<tr>
<td>Surface temperature</td>
<td>Fluke 66 infrared thermometer</td>
<td>±1 % of read in or ± 1ºC (the highest value).</td>
</tr>
</tbody>
</table>

Table 4. Measurements instruments

Figure 3. Aerial view of area and (left). Setting area: buildings (gray), vegetation (green), location of set points (observed -Op- and simulated -Sp-) (right).
The modelling of the physical space was performed in a version 180 × 180 × 30. The resolution of the area is 4x4x4 m, the number of total grid is x:170; y:90; z:30, 4 nesting grid, and 6 receptors (Fig. 3). The properties and the conditions of the simulation used in the configuration of the base case are listed in Table 5.

Table 5. Input parameters for ENVI-met simulation

<table>
<thead>
<tr>
<th>MAIN DATA</th>
<th>Wind Speed in 10 m ab. Ground [m/s]</th>
<th>2.8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wind Direction (0:N; 90:E; 180:S; 270:W)</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Roughness Length z0 at reference point</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Initial Temperature Atmosphere [K]</td>
<td>299</td>
</tr>
<tr>
<td></td>
<td>Specific Humidity in 2500 m [g water/kg air]</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Relative Humidity in 2m [%]</td>
<td>25.7</td>
</tr>
</tbody>
</table>

| BUILDING DATA | Inside Temperature [K] | 297 |
|               | Heat Transmission Walls [W/m²K] | 2 |
|               | Heat Transmission Roofs [W/m²K] | 0.76 |
|               | Albedo Walls | 0.2 |
|               | Albedo Roofs | 0.3 |
|               | Initial Temperature Upper Layer (0-20 cm) [K] | 300 |

| SOIL DATA | Initial Temperature Middle Layer (20-50 cm) [K] | 297 |
|           | Initial Temperature Deep Layer (below 50 cm) [K] | 295 |
|           | Relative Humidity Upper Layer (0-20 cm) | 40 |
|           | Relative Humidity Middle Layer (20-50 cm) | 50 |
|           | Relative Humidity Deep Layer (below 50 cm) | 50 |

* U-values= 0.76 W/m²K (wooden roof with 5 cm of insulation and terracotta tile).

To adjust the theoretical model, the simulated air temperature curve by ENVI-met 3.1 (Sp) was contrasted with the real air temperature curve obtained from the data recorded from a fixed observed point (Op) located within the study area.

Figure 4 and Table 6 show the results of comparing the air temperature curve obtained by the simulation (Sp) and the real measured curve of the day evaluated (Op). The simulated curve (Sp) has similar correspondence with the observed curve (Op). R² = 0.99.

Table 6. Adjustment between the reference point (Op) and ENVI-met model (Sp)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Observed Point</th>
<th>Simulated Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>average</td>
<td>32.4</td>
<td>32.3</td>
</tr>
<tr>
<td>max</td>
<td>37.6</td>
<td>37.4</td>
</tr>
<tr>
<td>min</td>
<td>28.3</td>
<td>28.5</td>
</tr>
</tbody>
</table>
Proposed roof scenarios

To assess the impact of the different roof retrofit strategies on urban thermal behaviour, 4 scenarios were simulated. It should be noted that in order to compare the effects of different roofing technologies, the evaluated scenarios were simulated without urban trees (Table 7).

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Roof technology</th>
<th>Roof U-value [W/m²K]</th>
<th>Solar reflective</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td>Wood roof - Base case</td>
<td>0.75</td>
<td>0.30</td>
</tr>
<tr>
<td>M1</td>
<td>Concrete roof plus White geotextile membrane</td>
<td>0.85</td>
<td>0.86</td>
</tr>
<tr>
<td>M2</td>
<td>Aluminum membrane</td>
<td>0.85</td>
<td>0.76</td>
</tr>
<tr>
<td>G1</td>
<td>Concrete roof plus Sedum sp. Green roof</td>
<td>1.66</td>
<td>0.46</td>
</tr>
<tr>
<td>G2</td>
<td>Nassella sp. Green roof</td>
<td>1.66</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Thermal performance of simulated scenarios

The variation of thermal behavior for each of simulated scenarios is presented. Their performance is contrasted with the base case (B0). The behaviors of all analyzed situations are presented in Table 8 and Figure 5.

The ENVI-met model results show that:

- **Regarding air temperatures (Ta):** During the heating period (16:00-17:00 hs), the maximum differences in urban air temperature with respect to the base case -B0- are in the M2 scenario, with a ΔTa maximum of 0.56 ºC. In the cooling period (7:00 - 8:00 hs) the maximum temperature differences are achieved by the G2 scenario, registering 0.2ºC cooler than the base scenario.

- **Regarding mean radiant temperatures (Tmrt):** During the heating period (16:00-17:00 hs), the total of the scenarios increases the Tmrt maximum, between 0.20 and 0.40 ºC. However, green and cool roofs technologies have lower Tmrt average than the base case -B0- (0.11 and 0.44 ºC). During the cooling period the scenarios with membranes M1 and M2 achieve the greatest temperature decreases (0.46 ºC).
Table 8. Differences in air temperature and radiant mean of proposed scenarios (M1, M2, G1, G2) with respect to the base case (B0).

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>M1_U0.85</th>
<th>M2_U0.85</th>
<th>G1_U0.3</th>
<th>G2_U0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differences of air temperature; ºC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tº average</td>
<td>-0.23</td>
<td>-0.30</td>
<td>-0.32</td>
<td>-0.33</td>
</tr>
<tr>
<td>Tº max</td>
<td>-0.45</td>
<td>-0.56</td>
<td>-0.45</td>
<td>-0.42</td>
</tr>
<tr>
<td>Tº min</td>
<td>0.06</td>
<td>0.06</td>
<td>-0.16</td>
<td>-0.20</td>
</tr>
<tr>
<td>Differences of Mean radiant temperature; ºC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tº average</td>
<td>-0.44</td>
<td>-0.42</td>
<td>-0.18</td>
<td>-0.11</td>
</tr>
<tr>
<td>Tº max</td>
<td>0.37</td>
<td>0.40</td>
<td>0.27</td>
<td>0.20</td>
</tr>
<tr>
<td>Tº min</td>
<td>-0.46</td>
<td>-0.46</td>
<td>-0.35</td>
<td>-0.21</td>
</tr>
</tbody>
</table>

Figure 5. Air temperature curve (left) and mean radiant temperature (right), according to proposed scenarios to 6 meters high.

**Conclusion**

This study has used an integrated modelling approach by means of link Energy Plus and ENVI-met in studying urban temperature reduction by green and cool roofs under arid contexts. Tools for co-simulation procedures were provided, where the Energy Plus software calculates thermal parameters of the different roofing technologies to be applied in urban simulations with ENVI-met. The objective is to use the potential of each software to obtain more adjusted and reliable results.

The results achieved in this investigation show that, at object scale, the albedo of the membranes is higher than the vegetated roofs. The most efficient roofing material to reduce urban temperatures is the white membrane, with a Ts (surface temperature) = 40.7°C.

At buildings scale, it was demonstrated that the use of Energy Plus software is a reliable tool to predict the values of heat transfer of green roof technologies that are adapted to an arid environment. Added, the generation of the input data of materials and technologies of roof allowed the modeling of scenarios with representative parameters of local roofing technologies. Further, a measure of how these latter roofing technologies impact over the urban climate was obtained.
The thermal behaviour at urban scale is congruent with the experimental tests, in which the M2 and G2 technologies exhibit an inferior rise of their superficial temperature. The scope of this investigation shows that, during the heating period, the roof that lessens its temperature compared to the base case is that with insulation and geo-white membrane M2- (differences of air temperature with base case= 0.56°C), while in the cooling period the most favorable scenario is that which incorporates a vegetated cover with the native species: *Nassella tenuissima* -G2- (differences of air temperature with base case= 0.33°C). These magnitudes are comparable with those obtained by Morakinyo et. al, 2017, that evaluated the urban thermal benefits produced by the application of green technologies in different cities worldwide.

The research shows that traditional roofing technologies could be improved with the incorporation of insulated cold roofs or green roofs without insulation. Both technologies tested in this research demonstrated similar beneficial effects in terms of urban air temperature. However, green roofs also provide other ecosystem services to the urban environments, such as the oxygen production and the reduction of CO$_2$ by means of biomass incorporation, among others.

Adjusting the input data of ENVI-met, with the Energy-Plus program and the experimental results, allowed to enhance the quality and the accuracy of the ENVI-met library according to the local reality, improving the results of the urban simulations. It is important to point out that meanwhile more Energy-Plus input data comes from experimental results and not from parametric approaches or bibliography, the simulated scenario will be closer to real case, this will allow better inferences and design decision making by urban planners.

In the area where the research project was carried out, these cover technologies (cool or green roofs) are incipient. Construction professionals or users recommend incorporating projects more for their aesthetic value or the advice of sellers than for the benefits they provide at the urban or building scale. In addition, green roofs have become very popular, but there are very few successful projects in the area. Moreover, the technology incorporated is regularly foreign, and thus has not been locally tested to guarantee its success and permanence. Consequently, there is still no local information on execution and maintenance costs. In future projects, it might be wise to carry out an economic study of these roof technologies, considering the implementation and maintenance costs of each technology, and the quantification of environmental benefits that they provide.

References


Esteves, A. 2017. Arquitectura Bioclimática Sustentable. Mendoza
Flores Asin, J. E., Martinez, C. F.; Cantón, M. A. y Correa E. N. 2016. Desempeño térmico de cubiertas verdes en ciudades de zonas áridas. Hábitat sustentable 6,2; 6-15. ISSN: 0719-0700
Can structures be created from their site?

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Abstract: Sustainability in buildings largely focuses on the operational period, rather than the construction and deconstruction phases. In the past, using local materials was the obvious and sustainable choice, 95% of which could usually be reused or recycled. Compare this with materials chosen in the past 100 years, where only 70% can be reused or recycled (Berge, 2009). This paper explores the reasons for using sustainable and local resources for building materials, focusing on a specific site within Snowdonia National Park, Wales.

The vernacular and historical architecture of North West Wales is discussed, along with geology, with a description of designs that have evolved from this. Traditional local materials are mapped, followed by discussion of the attributes and resources on the site.

A basic structure is proposed, using the site materials only, specifying stone foundations, bracken cob walls with clay plaster, a timber frame roof with reclaimed slate and shingle weather proofing. Local architecture was informative for this design. Assessment in regards to sustainability was limited, due to lack of data on natural building materials in relation to more commonly used materials on comparison sites.

Keywords: local, sustainable, materials, low-carbon, Wales

Introduction

The building industry currently has a massive and negative environmental impact on our planet. Climate change awareness means that major changes are being achieved in the energy efficiency of buildings, though the focus is on the operational phase and doesn’t yet extend sufficiently to the materials that are used to achieve this (Hammond and Jones, 2011). This paper explores the reasons for using sustainable and local resources for building materials. The focus is on the vernacular and historical architecture of North West Wales and what has changed. A site is introduced, in detail, which lies in the small hamlet of Llandecwyn (Figure 1), within Snowdonia National Park, overlooking the Dwyryd estuary. A 25 mile radius of source materials is mapped. In addition, the site materials are studied. To conclude, a proposal is made for a structure, using the site materials.

Why materials need to be sustainable

Architecture has moved away from traditional and sustainable building practices, which used local materials. A pallet of materials from outside the locality that use state changing processes is currently the norm. This was not common practice 200 years ago, when machinery was basic and transport constrictions meant that local solutions had to be found, except where good water communications were established (William, 2010). Processes that we use today had not begun yet, such as the cement industry.

Cost and standardised materials available from building yards currently dictate design, rather than sustainability. Steel and concrete can produce tall and wide buildings and glass walls have become increasingly energy efficient. Structures from these materials deplete resources substantially and create high carbon emissions (Table 1) (Thiel et al., 2013). Buildings can be difficult to demolish and return to source at the end of a building’s life. Climate change awareness means that the economic argument no longer
makes sense and improving the efficiency of buildings in the construction phase is an essential step to reduce the building sector’s carbon footprint on the planet.

The operational phase of a building historically has high carbon emissions (Nässén et al., 2007). With the UK targets now set for reducing these by 2050, energy efficient structures are being built, so the material’s carbon emissions can be more damaging to the environment than those of the operational phase (Hammond and Jones, 2011; Mandley et al., 2015; Chastas et al., 2018). Materials are not usually selected with demolition and reintegration in mind and waste is an issue (Ajayi et al., 2018; Gálvez-Martos et al., 2018). Waste could be reduced by over 40% in conventional construction if it was considered at the design phase (Ding et al., 2018).

The life cycle of a building has three phases; construction, operation and demolition. Life cycle assessment (LCA) measures energy used from extraction of a material to its point of sale; called embodied energy, from cradle to gate. It would be more relevant to assess from cradle to grave/cradle, a closed loop system which extends from extraction, through building use, to reintegration of the material back into the environment. Berge (2009) states that with older buildings, 95% can be recycled. Yet with materials from the last 100 years it is hard to recycle more than 70%, due to the hazardous and composite materials involved.
Increasingly, embodied carbon/energy is being factored in (Dixit, 2017), taking into account all the energy requirements of the material, combining the carbon sequestration, eg. timber in its growth phase (Cleveland and Morris, 2009).

Renewable resources are recreated, timber and hemp for example, and have the benefit of absorbing carbon while growing. Finite resources are being harvested for the construction industry and they can be used up, eg. stone, copper, zinc, lead and earth, but quantities vary substantially. As an example, earth is abundant and can be used in an unchanged state and easily reintegrated to its source (Hamard et al., 2016: Arar, 2017). Zinc and copper are much rarer and require more embodied carbon to produce.

Issues can be addressed by local sourcing/extraction and doing less to change the original state of materials for the construction process (Morel et al, 2001). This makes demolition and the reintegration of the material into the locality simpler, less wasteful or less material to relocate/recycle. For example, an unmaintained house built with timber and thatch, will decay and return to its natural state easily within decades. A concrete structure will show minor decay in the same timescale (Zhang et al., 2018).

### Table 1. Primary energy and CO$_2$ emissions linked to activities in the building sector in year 2000 (Nässén et al., 2007).

<table>
<thead>
<tr>
<th>Sector</th>
<th>CO2 total (kton C)</th>
<th>Cumulative share of CO2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete and cement</td>
<td>267</td>
<td>28.5</td>
</tr>
<tr>
<td>Construction</td>
<td>219</td>
<td>51.8</td>
</tr>
<tr>
<td>Iron and steel production</td>
<td>109</td>
<td>63.4</td>
</tr>
<tr>
<td>Freight transport by road</td>
<td>61</td>
<td>69.9</td>
</tr>
<tr>
<td>Other non-metal mineral products</td>
<td>32</td>
<td>73.3</td>
</tr>
<tr>
<td>Petroleum refining etc</td>
<td>26</td>
<td>76.1</td>
</tr>
<tr>
<td>Air transport</td>
<td>20</td>
<td>78.1</td>
</tr>
<tr>
<td>Steam and hot water supply</td>
<td>18</td>
<td>80.1</td>
</tr>
<tr>
<td>Non-ferrous metal industry</td>
<td>18</td>
<td>82</td>
</tr>
<tr>
<td>First processing of iron and steel</td>
<td>15</td>
<td>83.7</td>
</tr>
<tr>
<td>Mining of fossil fuels</td>
<td>15</td>
<td>85.3</td>
</tr>
<tr>
<td>Water transport</td>
<td>13</td>
<td>86.7</td>
</tr>
<tr>
<td>Mining of non-metal minerals</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td>Electricity production</td>
<td>12</td>
<td>89.3</td>
</tr>
<tr>
<td>Glass and glass products</td>
<td>10</td>
<td>90.4</td>
</tr>
<tr>
<td>Wholesale and retail trade</td>
<td>10</td>
<td>91.4</td>
</tr>
<tr>
<td>Chemicals and paint</td>
<td>8</td>
<td>92.2</td>
</tr>
<tr>
<td>Wood and wood products</td>
<td>7</td>
<td>93</td>
</tr>
<tr>
<td>Structural metal products etc</td>
<td>7</td>
<td>93.8</td>
</tr>
<tr>
<td>Agriculture</td>
<td>7</td>
<td>94.5</td>
</tr>
<tr>
<td>Paper and paper products</td>
<td>4</td>
<td>94.9</td>
</tr>
<tr>
<td>Ceramics</td>
<td>4</td>
<td>95.4</td>
</tr>
<tr>
<td>Other sectors</td>
<td>43</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>938</td>
<td></td>
</tr>
</tbody>
</table>

International Conference for Sustainable Design of the Built Environment - SDBE London 2018 695
Comparing data from material assessors will indicate how sustainable a material is. Assessors include: the Building Research Establishment (BRE: Green Guide) that provide the BRE Environmental Assessment Method (BREEAM), GreenSpec, which is independently run by architects and the Inventory of Carbon and Energy (ICE) which is at Bath University. There is pressure to make our current buildings more energy efficient, but character and internal space are arguments raised against sustainability. For example, insulation such as expanded polystyrene 40kg/m2 (BRE rating of 12kg/co2) may be chosen rather than straw bales (BRE: Green Guide rating of -53kg/CO2) in order to retain room space. Thermal comfort can be achieved using local materials and minimal modern materials (Leo Samuel et al., 2017).

Materials and Architecture in North West Wales

The Llandecwyn site is in an area called the Harlech Dome. It contains volcanic and sedimentary rock of Lower Palaeozoic age greenstones with quartz and metalliferous lodes (Matley and Wilson, 1946), resulting in a hard granite or sandstone that is tricky to dress. Softer shales and slates also encircle the dome.

Assessing suitability of a material in the local climate is essential; it may not be practical to build with wood or straw in a damp woodland if a building is infrequently occupied. Local climate and predicted climate change need taking into account and the vernacular architecture provides clues. Farming and longer term settlements started in Wales 6000 years ago (Morgan, 2001). Round houses had stone walls, a thatched roof and a central fire; smoke escaping through thatch rather than a chimney (Karl and Brown, 2010). Stone farmhouses were roughly built without mortar, the gaps stuffed with moss. Fine stonework and dressed stone showed status, along with lime render. This was imported in 18th century via Porthmadog (Walwyn 2013).

Wiliam (2010) states that the fragile homes of the poor frequently collapsed; made of earth, shaly/rubble stone, rushes, gorse, and timber. Some earth buildings remain in Botwnnog, 27 miles west of Llandecwyn; a few with thatched roofs with wicker chimneys. Most structures faced south and had little or no glass. Cruck timber frame houses were built, the earliest reference being 1305 in Harlech (Haslam et al. 2009). Remaining examples of single family dwellings, generally 15-40 sqm, with imported softwood roof trusses and a low-pitched slate roof, often with a croglofft (Barnwell and Suggett, 2014). Partitions were often lath and plaster. House plans were not used, only traditional knowledge (called ground rules) until the 19th century (Jenkins, 1967). Some cob buildings in the UK are 500 years old (Weismann and Bryce, 2006), but few remain in North Wales; stone buildings outlived everything.

The robust, 13th century castle of Harlech has grey/green sandstone wall fortification and a gatehouse made from timber. Maes y Neuadd (2 miles from the Llandecwyn site), Talsarnau, has been a hotel for about 50 years. It was built from granite in the 14th century, with an oak framed slate roof and was originally a hall house (Wiliam, 2010). It was enlarged considerably in 16th and 18th century with similar materials. A 20th century addition uses a cement block structure faced with stone, to hide the modern material. Farmhouses earlier than 1850 are rare; they were rebuilt with stone, with a slate floor (Wiliam 2010). A constant heat source from the fireplace meant that the large quantity of thermal mass in the walls and floor maintained a comfortable temperature. Ty unos, (meaning ‘one night house’) was a 17th-19th century tradition. The house would be built overnight on common/waste land. If there was a door and a fire burning by dawn, then it could remain and the land claimed.
Slate extraction from slate quarries in Blaenau Ffestiniog marked an enormous financial change for the area and in roofing style. Local houses benefitted while the rest of the UK had to wait until transport links improved affordability. Slate export was recorded in 1821 as 10,000 tons per year, by 1854, 51,000 tons (Walwyn, 2013). It was transported by rail to Porthmadog, from 1836, then sailed around the world. Ballast was required for the return journey, so the ships were loaded with timber, that was superior in quality to local supplies. The result is long spanning roof structures built with timber, such as pitch pine from North America and covered with local slate (Maurice-Jones, 2008). Wheeled cars appeared in the area in 1799, then from 1870 railways made it possible to export/import materials in greater quantities.

In the last 150 years, local buildings have been predominately constructed from brick and concrete block. Wall finishes include cement render/roughcast claddings, pebble dash or faced with stone to reflect traditional vernacular. Roofs are generally of imported softwood timber construction with slate. Haslam et al. (2009) describes variants including Portmeirion, built 1926 -76, by Williams-Ellis, as ‘render on timber, masquerading as stone’ (Figure 2). Coleg Harlech has a concrete sub Brutalist theatre, 1973, built by Colwyn Foulkes and partners (Figure 3). The Snowdonia planning office, by Dylan Roberts of Gwynedd county architects, has an array of stone materials, including granite, along with an exposed laminated timber frame structure (Figure 4).
Despite increasing awareness around construction sustainability and materials, buildings win awards for their uniqueness, with little reference to environmental issues. For example, the Mondrian inspired Cefn Castell, Criccieth (Stephenson Studio, 2014), has a concrete foundation, a steel frame, entire walls of glass and flat roofs. There are some remaining stone walls from the old cottage (Figure 5).

Method and site description

Materials on the Llandecwyn site were mapped and assessed. A structure was then proposed as part of the conclusion.

The four acre site in Llandecwyn, has a south to south west grassy slope towards the coast, an altitude of 70 metres and an abundance of trees, including mature oak and ash. The stone on the land is a transition from the granite on the coast and the slate to the east which results in a poorer quality shale type stone. The site has traditional dry stone walls acting as boundaries around half of the land. There are two buildings with turf roofs, built in 1997; a small straw bale barn, originally to house livestock (currently used as a cooking and eating space) and an open sided, timber post goat shelter, built against a natural rock wall. The site is not at risk regarding flooding and coastal erosion (Natural Resources Wales, 2017), though the site is quite exposed and increased high winds and rain are predicted as the climate changes.

In 1996, planting increased the tree stock by 1000, with a land stewardship goal; aiming to increase biodiversity by resting the land from grazing animals and was historically common practice (Gadgil et al., 1993). Subsequent plantings each year include nuts, fruit and willow. Trees were planted closely, encouraging fast growth and now need thinning. This timber is now available for construction and biofuel purposes. Ash, oak, birch and chestnut can be used for framing, oak and chestnut for shingles and weatherboards (Heroux, 1978; Niemiec and Brown, 1993; Law, 2010).

Harvesting resources from the site (Table 2) has immense cradle to grave advantages, regarding transportation, packaging, storage and disposal. If abandoned, the structure would principally break down and return to the earth on which it stood (the exception being some recycled materials). Table 3 and Figures 6 & 7, comprise detailed information of the site materials and their locations. Site earth is found to contain 12% clay, by jar test, which is suitable for cob walls.

‘...early modern society was characterized by the ability to find some purpose for virtually every natural material and agricultural by-product.’ Woodward (1998)
<table>
<thead>
<tr>
<th>Material</th>
<th>Use</th>
<th>Quantity</th>
<th>Locality, etc.</th>
<th>BRE: Green Guide rating/Kg of CO₂ eq. (60 years) cradle to gate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone</td>
<td>Walls, floor, foundation</td>
<td>Abundant</td>
<td>Reclaimable from a derelict building and old dry stone walls. Four exposed stone ridges where material can be extracted. It is shaly rubble, can be knocked out using a pickaxe</td>
<td>No rating</td>
</tr>
<tr>
<td>Slate</td>
<td>Roof</td>
<td>Scarce</td>
<td>A small amount at the derelict building</td>
<td>A+/3.8</td>
</tr>
<tr>
<td>Earth</td>
<td>Walls, mortar</td>
<td>Abundant</td>
<td>A jar soil test showed that the subsoil onsite contains approximately 12% clay, suitable for use in unstabilised rammed earth walls, cob walls and for creating clay render, plaster and paint</td>
<td>Walls A+/4.7</td>
</tr>
<tr>
<td>Bracken</td>
<td>Wall fibre, insulation, mortar strengthening</td>
<td>Abundant at present, but is gradually being suppressed, to allow areas for annual crops</td>
<td>It is suitable as fibre in cob walls (McCann, 2004) also under thatching and insulation, (Woodward, 1998)</td>
<td>No rating</td>
</tr>
<tr>
<td>Hemp</td>
<td>Wall fibre, insulation</td>
<td>To be grown as an annual crop</td>
<td>Pococke (1889), mentions the great quantity of hemp grown in North Wales, used for nets, sacking and cloth. Cannabis Sativa L. Hemp can be grown onsite but requires an annual licence from the home office. Allin (2005), explains the process</td>
<td>No rating</td>
</tr>
<tr>
<td>Straw and rushes</td>
<td>Thatching</td>
<td>To be grown as an annual crop</td>
<td>Wheat straw thatching material is viable, (Reynolds, 1995), along with rushes</td>
<td>No rating</td>
</tr>
<tr>
<td>Rushes</td>
<td></td>
<td>A little on the land, abundant just beyond boundaries.</td>
<td>Juncus (rushes); strong with cylindrical stems which grow wild.</td>
<td>No rating</td>
</tr>
<tr>
<td>Moss</td>
<td>Insulation</td>
<td>Abundant</td>
<td>Grows naturally and in abundance on rocks, trees and the woodland floor, (Bitzer et al., n.d) explains its benefits as insulation</td>
<td>No rating</td>
</tr>
<tr>
<td>Wool</td>
<td>Insulation</td>
<td>A little on the land, abundant just beyond boundaries.</td>
<td>Sheep graze up to most boundaries and the land has supported 8 sheep in the past.</td>
<td>A+/3.9</td>
</tr>
<tr>
<td>Bottles</td>
<td>Windows</td>
<td>A steady accumulation</td>
<td>Glass bottles and jars can be used as windows.</td>
<td>No rating</td>
</tr>
<tr>
<td>Cans</td>
<td>Walls</td>
<td>A steady accumulation</td>
<td>Non load-bearing walls with clay/earth for mortar.</td>
<td>No rating</td>
</tr>
<tr>
<td>Plastics/ fabric</td>
<td>Insulation</td>
<td>A steady accumulation</td>
<td>Plastics and fabric waste used as insulation.</td>
<td>No rating</td>
</tr>
</tbody>
</table>
Figure 6. Site map showing stone, slate and sheep/wool sources (Buhler and Wynn, 2015).
Figure 7. Site map; organic materials for construction (Buhler and Wynn, 2015).
Proposed structure and conclusion

A viable structure can be created from this site, as was common practice before modern transportation was available. Sourcing materials locally can make construction more sustainable, especially if materials come from the site. The vernacular architecture and the material history proved informative, regarding possibilities with structures with local materials and holds clues to a sustainable future in construction.

The foundation is a rubble trench, with a French drain beside it (Figure 8). A foundation, dry stone wall supports a cob wall, strengthened with dried bracken fibre and is rendered/plastered with clay.

The roof is a roundwood frame structure, insulated with sheep’s wool, moss and waste material. Roof shingles cover most of the roof and the limited quantity of reclaimed slate is used in a small area at the top of the roof, to form a robust cap.

The external walls would be clad in timber in the future, if the clay render is extensively degraded by driving rain, the south elevation being particularly exposed. Window frames (with external timber shutters) are made with timber and waste glass and bottles are rendered into them, using small stones and clay mortar, strengthened with chopped bracken fibre. Internal walls are woven, using hazel and willow, and plastered with clay.

The building is heated by a stone, wood-fired cooking stove with a wicker chimney, fireproofed with clay. Wood from the land provides the fuel.

The design is achievable, but is limited to a basic shelter and is not detailed for materials for plumbing, electrics and finishes. Further work could include these aspects, along with sustainability implications.

There are shortcomings in this paper, regarding data on the materials. BRE: Green Guide is designed for mainstream construction and it was hard to find information on individual materials and traditional techniques. Further work is needed, using all assessors and other types of investigation. In addition, assessments could be made as to how viable
this type of construction is; regarding the land resources available to the current population and whether lifestyle changes are necessary.

Figure 8. Drawing of proposed cob structure (not to scale), with an example of a window made with used bottles and glass.

References:


Are P3s Sustainable? A study of facility resource use effectiveness at a Canadian healthcare corporation

Alexander C. White

Abstract: In recent years an increasingly diverse range of infrastructure delivery structures are being used with little empirical understanding of their long-term implications on operational performance, particularly resource use. Across Canada, and the province of Ontario in particular, this is marked by a notable shift favouring Alternative Finance and Procurement (AFP) approaches, including the use of Public-Private Partnerships (P3s). With focus on resource use during the operational phase, this paper provides a case study of a specific healthcare corporation in Ontario, Canada including an early P3 hospital delivered by Infrastructure Ontario under the Design-Build-Finance-Maintain (DBFM) structure, as well as a conventionally procured and operated facility. The article identifies the practical influences and challenges associated with the facility’s procurement and operations in order to consider broader implications for future research and to support planning and policy work. Using empirical data on Facility Management labour and energy use - supplemented by facility user surveys, interviews of key stakeholders and contractual study - findings show consistently better performance at the P3 facility, though after a short bedding-in period for energy performance. Many best practices were transferred from the P3 facility to the conventionally procured facility to improve data tracking and reporting, but internal accountability remains a challenge and budgeting factors negatively impact the conventionally procured facility. The mix of strong financial penalties and incentives within the P3 contract between Project Co and the hospital, which all proponents’ bids were subject to in the procurement phase, are identified as likely drivers for high performance of maintenance activities and energy use directly, and facility user satisfaction levels indirectly. Notably, the dramatic improvements in energy use at the P3 site is not matched by the facility’s water use, for which, unlike energy, conservation is not incentivised in the contract.

Keywords: Infrastructure delivery, facility operations, resource use, Public-Private Partnerships

Introduction

Governments around the world spend over a trillion dollars of public money a year on social infrastructure, such as hospitals (Woetzel et al., 2016). Shaoul et al. (2007) identified an increasing diversity of infrastructure delivery structures being used with little empirical evidence of their long-term implications on effectiveness and cost, which still holds true. Across Canada, and the province of Ontario in particular, this is marked by a notable shift favouring the use of Public-Private Partnerships (P3s), often positioning them as means to encourage innovation across the lifecycle of major infrastructure projects (Himmel and Siemiatycki, 2017). Yet, in particular, very few ex post accounts of operational facilities exist in the academic or industrial literature, particularly of P3 healthcare facilities (Roehrich et al., 2014).

The purpose of this paper is to empirically identify relationships between variations in facility delivery structure and operational outcomes. This is achieved through a case study of a healthcare corporation in Ontario, Canada with two large hospitals, one conventionally procured and maintained by hospital staff and one facility delivered as a P3. Using empirical data for specific Facility Management (FM) processes, supported by facility user surveys and interviews with key stakeholders, the author provides description of the facilities’ background and compares performance between the sites with analyses supported by contractual study and the author’s in-depth knowledge of the facilities and their management structures.
Recognising the limitations of one case study, analysis within considers broader implications for future research.

Having reached Substantial Completion in 2013, the study includes one of the more mature P3 hospitals in Canada and so is well positioned to identify practical influences, successes and challenges associated with infrastructure operations and maintenance under the different delivery models. Though advocates increasingly identify P3s as a tool to encourage innovation, specifically toward cost reduction and enhanced quality (Regan et al., 2011), empirical evidence to support such claims is limited and so it is unclear whether these innovations are actually being realised (Siemiatycki, 2015). This makes the study particularly important for policy makers in the field.

**How to Measure Facility Resource Use Effectiveness**

Research in the field is largely theoretical and most of the limited empirical contributions have focussed on initial development costs due to limited availability of data from the operational phase (Chen et al., 2015). As such, minimal *ex post* analysis has been conducted on the long term implications of ownership structures on the life cycle effectiveness and cost of the infrastructure (Shaoul et al., 2007) although the operations, maintenance and upgrading phases generally surpass upfront development costs over the life of the infrastructure, thus having huge significance on the overall sustainability of the project (Rahman and Vanier, 2004). The operational phase is the focus of this study, with the leading research question: *Is there a relationship between variations in hospital delivery structure and effective resource use during operations, within a specific healthcare corporation in Ontario, Canada?* The question is addressed using a mixed methods approach involving a retrospective case study (Creswell, 2014, Hammersley, 2004) of the site with both quantitative and qualitative analyses. The Case Study is a commonly used method (Shang and Zhang, 2013, Olesen, 2014) that enables researchers to focus on details of specific systems and the decision-making processes associated with them in order to develop a concrete study of discrete facilities (Yin, 2009). This approach can provide a practical, context dependent example with great value for policy-makers (Flyvbjerg, 2012) and has been used well with hospitals, including P3s (Chung, 2009).

Available quantitative data on facility maintenance staffing levels, energy use and user satisfaction was obtained and used to compare operations between the facilities. Analysis of this information is supported by semi-structured interviews of key personnel managing the facilities within the healthcare corporation (details in Appendix A). For the P3 facility, this included FM Committee members from both the hospital and the Project Company (Project Co) who were involved with the project throughout the procurement, design-build and operational phases. Representing both the public and private sector partners, the interviewees were asked questions specific to the facilities included in the case study as well as general questions on the use of P3s for healthcare, with emphasis on operational outcomes.

**The Subject**

The healthcare corporation studied is a regional, tertiary academic health science and research centre operating multiple campuses within a major urban centre in Ontario, Canada. Founded in the mid-19th century, the organisation serves hundreds of thousands of patients annually with over 4,000 staff, 700 physicians and 600 volunteers and average expenditures of over $500 million. Its two main hospitals, located under one kilometre from one another, are included in this study. Facility 1 is a downtown acute care hospital with over 600 beds, surgical centre, emergency department and birthing programs as well as numerous research
institutes (Withheld, 2017). The site was initially occupied at the turn of the 20th century and the current facility was developed in multiple phases since that time, with the majority of its current 118,000 m² (Indoor Floor Space, IFS) structure completed in 1990 (Savage, 1990) and the latest renovation and major expansion completed in about 2010 (Interviewee 2, 2017).

Facility 2 is a low-rise, 80,000 m² (IFS), over 300 bed, tertiary-care mental health hospital providing inpatient and outpatient care to those suffering with a severe mental illness or addiction, as well as medical outpatient clinics and diagnostic imaging services to the community, administrative, education and research space (Withheld, 2017). The facility reached Substantial Completion in 2013, replacing a former regional psychiatric hospital about half the size and made up of a collection of 60 to 150-year-old buildings that housed inpatient and outpatient services. The new facility has 49% more beds and 62% more outpatient services than its predecessor with a vision to be recovery-oriented, destigmatizing and uplifting through the use of design elements to integrate mental health and community services plus improve the quality of care, user satisfaction and safety (Ahern et al., 2015).

The hospital’s redevelopment team initially began procuring the new facility under a traditional delivery model. Delivery as a P3, using the Design-Build-Finance-Maintain (DBFM) structure, was a funding requirement imposed late in the process by Ontario’s Ministry of Health and Long Term Care (MoH or Ministry). “We had already done all of the work and were ready to award a contract and the Ministry said ‘put on the breaks, this is going to be a DBFM’ and we had no choice in the matter; if we wanted Ministry funding that is... Honestly, I think the reason why we’re doing this model is because the Ministry didn’t have the funding” (Interviewee 2, 2017). The 2009 procurement (Withheld, 2009) was based on the contentious (Auditor General of Ontario, 2014) VfM calculations conducted for Infrastructure Ontario identifying a 14% cost savings over a hypothetical traditional delivery model (Infrastructure Ontario, 2011).

Though the construction phase met the targeted Substantial Completion date and Construction Variations only added about 0.5% to the capital price at bid (Withheld, 2015a), as with any project the construction was not without its challenges. With respect to the proposed benefit of bundling in DBFM contracts, Interviewee 2 (2017) stated, “The selling feature of this kind of procurement model was meant to be the synergies between the operations component and the mechanical and electrical designers making things the way they should was supposed to be part of the process. I don’t know if that actually happened because, although [the Service Provider] sat at the table in all of the design meetings they literally didn’t speak once... All of that expected expertise being brought during the design phase didn’t happen. I think [this led to] some of the issues that we have [in operations].”

Additionally, about six months before Substantial Completion a major subcontractor on the job went into receivership, leading to a scramble by all parties in the final months of construction and through commissioning. In retrospect, Interviewee 1 (2017) confirmed, “The building was not ready. OK. It was not ready [at Substantial Completion]. Despite the problems, Interviewee 1 (2017) points out that, “the DBFM [model] is what saved [the hospital], quite frankly, because had this been a Design-Build, with that receivership it would have been just horrific for the hospital to try and go back to [the builder]. Just think of how many resources the hospital would have had to marshal to understand the technical nature of the problems and to be able to take the design-builder to task. Now they just look at it and say ‘it’s broken, we’ve got penalties, you fix it.’”

Ultimately, as an early Canadian P3 and one of the first healthcare facilities in Ontario to be constructed on a brownfield site the project served as an example for procuring
authorities across Canada as they began to look at P3s in general and specifically for major redevelopment and renovation projects. Project Co challenged the initial design concept and created one that was more compact, intending to bring key activities closer together and reduce construction and operating costs (Withheld, 2015b). The site achieved LEED Gold certification in 2014 (Canadian Green Building Council, 2014), exceeding the Request for Proposal (RFP) obligation of LEED Silver (Withheld, 2009).

**Key Metrics**

In order to answer the research question the study focussed on two primary resources used in the management of the subject facilities, resources that are required for the facilities to provide the services necessary to clinical staff and patients. Those resources are unionised labour within the FM team, and energy, in the form of electricity and natural gas. These resources are also two of the most significant expenditures in the FM budget and therefore good proxies for comparable core facility operating expenditure, which were unavailable as the healthcare corporation studied does not produce either public or internal annual reports to track these figures (Interviewee 2, 2017). Additionally, in order to investigate the effectiveness of the FM resource use, the study includes satisfaction survey data of building users collected in previous years by the FM teams for analysis and comparison.

**FM Labour**

Labour is a key resource to run any healthcare facility and a very significant expenditure in any FM budget (Adams et al., 2010). Much has been said about private-sector involvement maximising efficiency (Avishur, 2000) of P3s (Fitzgerald, 2004) and Alonso et al. (2016) found evidence of a relationship between the use of P3s and reduced clinical staffing levels in hospitals. Clinical staffing is retained by the hospital in both facilities, as is typical in Canada, but this study looks at unionised FM staffing levels to identify if a similar relationship may exist. Total unionised FM staffing levels are compared between the facilities due to their similar unionised environment and to avoid discrepancies in management structure between the P3 and conventional facilities. In order to aid comparison between facilities of different size and other characteristics (e.g. age, hospital type) the total staffing levels are separately indexed by the size of the facilities and number of monthly Work Order (WO) events inputted into the Computerised Maintenance Management System (CMMS) at each facility.

Table 1 below includes a summary of unionised labour employed for FM services at the two facilities as well as indexed figures by average number of monthly WO events and total IFS. All data is using figures from 2018 collected directly from interviews and supplementary reports provided. The average number of monthly WO events completed per unionised FM employee at Facility 2 is 11.7% greater than at Facility 1 and total IFS per unionised FM employee is 23.6% greater at Facility 2. Both metrics indicate greater efficiency of labour use at Facility 2. Interestingly, a requirement in the P3 procurement of Facility 2 (Withheld, 2009) was that the winning consortium transfer the maintenance personnel over from the hospital that it replaced, subject to the employees’ approval, while retaining them in the same union as other hospital employees; thereby maintaining work conditions such as schedules, salary and other benefit levels. Of the 16 maintenance personnel at the old facility, seven stayed with the hospital, of whom four were on long term disability. The nine employees transferred to the winning consortiums’ FM Service Provider were augmented by three new hires (Interviewee 1, 2017). Therefore, 12 active unionised FM staff were maintained for a facility almost twice as large.
Table 1. Unionised FM labour levels for Facility 1 (traditional) and 2 (P3), 2018 (Interviewee 2, 2017, Interviewee 3, 2018, Withheld, 2018).

<table>
<thead>
<tr>
<th>Metric</th>
<th>Facility 1</th>
<th>Facility 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of unionised FM employees:</td>
<td>22</td>
<td>12</td>
</tr>
<tr>
<td>Monthly WO events completed (2018 average):</td>
<td>900</td>
<td>548</td>
</tr>
<tr>
<td>Monthly WO events completed per unionised FM employee:</td>
<td>40.9</td>
<td>45.7</td>
</tr>
<tr>
<td>IFS (m²) per unionised FM employee</td>
<td>5,362.0</td>
<td>6,627.1</td>
</tr>
</tbody>
</table>

Notably, having a CMMS is a contractual requirement for Facility 2 (Withheld, 2010a), central to the extensive reporting and accountability structures at the facility, and Facility 1 installed a CMMS as a best practice transfer from Facility 2 (Interviewee 2, 2017). The addition made data available for this comparison. The above findings were supported by Interviewee 2 (2017): “Demand Maintenance response times [at Facility 2] are excellent, they’re really good! … The strength [of the DBFM model] was bringing in the CMMS that was tried, tested and true and having the maintenance staff start out right away with it. The ability to keep track of all the work orders is really good and to be able to time when they were called in, when they need to be responded to and when they need to be rectified, putting that whole rigor around it - I love that. For the most part that’s been [Facility 2’s] greatest success… Anecdotally, the [Facility] Manager at [Facility 1] said there’s no way that our guys could meet the response and rectification times [achieved at Facility 2].” Interviewee 1 (2017) supported this saying that “Demand Maintenance works well because, they open a ticket, it’s logged, subject to performance penalties”. This penalty regime is a core component of the contract (Withheld, 2010a).

Interviewee 1 also raised the matter of ad hoc work and how it interacts with maintenance activities: “If [the staff] want to add an extra electrical outlet, well it’s going to cost money so it’s got to … be approved. They used to just get away with stuff because they had in-house electricians. The perfect example was in one of my conversations with [Interviewee 2] where she said “why should I pay you $800 to put in an electrical outlet if I’ve got an electrician down in [Facility 1] sitting around doing nothing to do it for free”. My question was “Why do you have an electrician in [Facility 1] sitting around doing nothing? Because that’s costing me money as a taxpayer.” In response to this matter, Interviewee 2 (2017) stated: “Ad hoc work to me is another thing that I feel like when we ask for it, the Service Provider is doing us a favour when they do it. I have no question when I’m at [Facility 1], I say to the guys “I need this done” and ‘BOOM!’ it’s done. Whereas [at Facility 2], the response is “if we do that, then your Demand Maintenance may be affected”. There’s more of a negotiation and I don’t like that...that’s a big difference in these procurement models. At [Facility 1] they work for me, here they don’t work for me. Do they get their Demand Maintenance responses done quicker because I don’t interrupt them like at [Facility 1]?” The data suggests that, with more WOs completed per unionised FM employee, this is the case. Interviewee 3 (2018) advised that at other hospitals where he worked, in order to avoid such distractions, FM employees were only allowed to conduct maintenance work and not conduct any new installations.

Facility User Satisfaction

Comparisons of FM effectiveness by quantity of resources used, or expenditure, is challenged due to the prevalence of deferred maintenance, and other underinvestment in the facility; Roberts and Samuelson (2015) estimated Canadian hospitals to have $15-20 billion of such accumulated deferred maintenance costs. According to Interviewee 2 (2017), this is
particularly true in conventionally delivered facilities such as Facility 1, where “millions and millions and millions of dollars” of deferred maintenance has accrued over time and Ministry funding must be used to supplement life cycle activities that “address the most risky parts of the hospital, but that still leaves us more at risk than we have [at Facility 2].” They “do an assessment of all the deferred maintenance [at Facility 1] but we don’t need to [at Facility 2] because it’s a DBFM... [DBFM] is a much better model - much, much better - because your actual lifecycle is built into the project. I know that my roof is going to be ok, I don’t have to try to wrestle the money through [MoH] funding or through our capital funds through our hospital, which always go to patient care equipment before it goes to fixing the roof. So, there is no doubt it is far superior in this model.”

In order to help investigate and compare the effectiveness of FM service delivery at the two facilities, the author used existing satisfaction surveys conducted by FM teams at the respective facilities between 2015 and 2017. The completion of these annual surveys identifying building users’ impressions of the facility, and associated FM activities, are a contractual requirement at Facility 2 (Withheld, 2010a), however, upon receiving the first report, the healthcare corporation conducted a comparable survey at Facility 1, though did not repeat it. From these surveys, the following three questions were compared in this study:

- What is your overall satisfaction with the facility and related services?
- What is your overall satisfaction with the Building Services Employees? and
- Requests for repairs are dealt with promptly and efficiently?

These questions were selected from the broader questionnaires as they were included in all available surveys and relate specifically to the outcomes of FM activities, associated processes and their management, with minimal impact from the type, age or configuration of the facility. All surveys were multiple choice with four answers to choose from; “Delighted”, “Satisfied”, “Dissatisfied” and “Very Dissatisfied”. Results are provided as a percentage of respondents that approved with the statement, meaning they selected “Delighted” or “Satisfied” as their answer. Table 2 shows the results of the selected survey questions for the various years performed. In all three cases, Facility 2 had a higher percentage of respondents that approved the statement in 2015 and had improved approval rates between 2015 and 2017. The positive, and generally improving, results through the operational phase at Facility 2 suggest that FM services are being performed effectively and that conditions are not degrading significantly.

Table 2. FM Survey results for Facility 1 and 2, 2015-2017, user approval ratings (number of respondents).

<table>
<thead>
<tr>
<th>Year</th>
<th>Facility 1</th>
<th>Facility 2</th>
<th>Facility 1</th>
<th>Facility 2</th>
<th>Facility 1</th>
<th>Facility 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>78% (405)</td>
<td>79% (265)</td>
<td>86% (406)</td>
<td>92% (243)</td>
<td>68% (404)</td>
<td>85% (263)</td>
</tr>
<tr>
<td>2016</td>
<td>80% (174)</td>
<td>94% (170)</td>
<td></td>
<td></td>
<td>73% (157)</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>95% (212)</td>
<td>97% (204)</td>
<td></td>
<td></td>
<td>93% (192)</td>
<td></td>
</tr>
</tbody>
</table>

**Energy Use**

Energy use is another of the most significant expenditures on FM budgets (Adams et al., 2010). There are multiple sources of energy used at the facilities, most notably Natural Gas, a raw fuel referred to as a primary energy source, and electricity, a converted product referred to as a secondary energy source. These are summed to provide the total energy use. Consumption statistics are collected from utility supplier bills that report Natural Gas use in...
and electricity use in kilowatt-hours (kWh), therefore Natural Gas is converted at 0.0375 GJ/m³ and electricity is converted at 0.0036 GJ/kWh to report total energy use in Gigajoules (GJ). A small amount of diesel fuel is used at the sites for generators but is very minor compared to the electrical and Natural Gas consumption, not tracked as closely and therefore excluded from the study. Also excluded is electricity produced by photovoltaic panels installed on the roof of Facility 2 in 2016 as they are owned by a third party leasing roof space from the hospital and feeding produced electricity directly into the grid for general use.

Building energy efficiency also depends on source selection due to production and distribution impacts, which vary by location. Source-site ratios are applied to the Natural Gas and electricity use to convert to Source Energy Use to account for the total primary fuel needed to provide the facility with heat and electricity by incorporating losses from the distribution, storage and dispensing of the primary energy sources (e.g. Natural Gas) and conversion, transmission and distribution losses for secondary energy sources (e.g. electricity). The Source-Site Ratio for Natural Gas in Canada is 1.02 and for electricity purchased from the grid is 2.05 (Energy Star, 2013). In order to aid comparison between sites, the Source Energy Use is divided by the IFS to produce a Source Energy Use Index (EUI), which provides the most equitable way to combine primary and secondary energy types into a common unit by ensuring that no building receives either a credit or a penalty based on its energy source or utility (Energy Star, 2016a). The Source EUI is reported in GJ/m².

Energy Star is an external benchmarking system for commercial buildings developed by the Environmental Protection Agency (EPA) in the United States and in 2013 Natural Resources Canada joined with the EPA to apply the scoring system to Canadian buildings as well (Energy Star, 2014). There are currently 13 property types in Canada for which Energy Star scores are calculated (Energy Star, 2017). Facility 1 is classified as a “Hospital (General Medical & Surgical)” while Facility 2 is classified as a “Residential Care Facility” as this applies to facilities primarily providing “permanent rehabilitative, restorative and/or ongoing skilled nursing care to patients or residents in need of assistance with activities of daily living” including “mental health and substance abuse facilities”. Using building details such as gross floor area, proportion air conditioned, number of beds, number of staff and location the online measurement and tracking tool Energy Star Portfolio Manager® calculates a predicted Source EUI using an equation based on a weighted ordinary least squares regression across a filtered data set of 142 observations (Energy Star, 2016b). These observations are for facilities in Canada with the same classification, based on data from the Survey of Commercial and Institutional Energy Use (SCIEU) commissioned by Natural Resources Canada and carried out by Statistics Canada based on energy consumption in 2009 (Natural Resources Canada, 2012). The Energy Star score, expressed as a number on a 1 - 100 scale, is assigned based on an efficiency ratio between the actual Source EUI and the predicted Source EUI value on a percentile basis (Energy Star, 2014).

Figure 1 provides a summary of energy use intensity, as measured by Source EUI, at Facility 1 and Facility 2 between 2014 and 2017, the four years for which Facility 2 has been in operation. Energy use intensity was generally flat (m_trendline,1,EUI = 0.018) over the four years at Facility 1, with an average value of 3.70 GJ/m². Energy use intensity had a strong downward trend (m_trendline,2,EUI = - 0.232) over Facility 2’s first four years of operations. Corresponding to the findings for facility energy use intensity, Figure 2 shows Energy Star scores for Facility 1 and Facility 2 over the same period. Energy Star Scores at Facility 1 had a slight downward trend (m_trendline,1,ES = - 3.1) over the four years, from outperforming 57% of similar buildings surveyed in 2014 to 44% in 2017. Facility 2’s Energy Star scores had a strong upward trend.
(m_{\text{trendline,2,EUI}} = 16.3) from outperforming only 22% of similar buildings surveyed in its initial year whereas in 2017 it outperformed 65%, with peak performance in 2016 when it was in the 85th percentile compared to similar buildings surveyed.

These findings show relatively flat, if not slightly worsening, energy performance at Facility 1 that, with an average Energy Star score of 47, is generally below the performance at comparable sites. This compares to dramatically improved performance at Facility 2 over the same period; though the facility had very poor performance compared to similar buildings in its first operational year, it quickly improved to be near the top of its class. Why might this be? The healthcare corporation pays providers directly for building energy and utilities at both facilities and so should be motivated to achieve energy efficiency by reduced energy costs at both sites. At Facility 2, Project Co is not responsible for purchasing energy directly but energy is managed by Project Co and efficiency is strongly encouraged through the contract between the hospital and Project Co, specifically within Schedule 36 “Energy Matters” (Withheld, 2010b). The strongest tool to incentivise energy efficiency is the Painshare/ Gainshare structure that compares actual electrical and natural gas consumption to an Annual Energy Target (AET) provided by all proponents at the time of bid and used in the selection of the winning team. The AET includes Discrete Energy Targets (DET) for both Electricity and Natural Gas consumption, which are adjusted annually over the contract term based on weather data, programme changes and building modifications (Withheld, 2010b). If actual electrical or gas usage is greater than 105% of the Adjusted DET (ADET) then Project Co must reimburse the hospital for 100% of the discrepancy, whereas if energy usage is 80%-95% of the ADET then Project Co and the hospital share savings equally. Any savings greater than 20% of the ADET go 100% to Project Co (Withheld, 2010b). These figures are provided within the Energy Analysis Reports provided annually (Withheld, 2015-2018).

As the findings show, there were problems with Facility 2’s energy use at Substantial Completion. As a LEED Gold facility it was expected to outperform most buildings but, as the
Energy Star score (22) shows, it did not perform well in the first year. In fact, many new facilities do not perform as designed, including LEED facilities, and require large investments of time and money to conduct extensive post-commissioning adjustments to the complex systems within modern buildings, though this is often not done (CIBSE, 2013). Instead, the contract strongly financially-incentivises energy performance and the exceedance of the energy target in 2014 resulted in a Painshare payment to the hospital of over $300,000, a significant portion of the operational portion of the Monthly Service Payment. As such, a program was developed to reduce the facility’s energy use going forward and a number of interventions took place over the second energy year to reduce consumption including: heat wheel repairs, amending occupancy schedules, adjustments to condensing and steam boilers’ and air handling unit sequencing and schedules, installation of LED lamps in key areas, optimisation of Building Automation System controls; and implementation of energy saving awareness programmes. As Interviewee 1 (2017) stated, latent construction defects “are par for the course. These occur past the warranty period, something that was working - was tested, tried and proven - and then broke some time later. We ran into some issues on the [heat] wheels, they all started falling apart ... but [Project Co consortia members] worked their way through the process. It's the ongoing P3 relationships between [the consortia members] that allowed that process to work successfully. I believe you would be less successful in a Design-Build type of environment because the design builder wouldn’t have any liability so [the hospital] would have to end up taking the equipment manufacturer to task.”

These initiatives led to significant savings in 2015 and a much smaller Painshare fee. The gains made, along with the incentive of higher energy prices, meant many of the programmes continued in 2016 leading to further reductions in energy use to below the adjusted AET for the first time that year. This reduction led to over $400,000 in savings in energy costs versus the modelled expenditure, of which over $100,000 was provided to Project Co as its first Gainshare payment. Although benchmarks other than the AET are not used much at the site, the inclusion of AET with the Aggregate Energy Model in the competitive tender process did result in an Adjusted AET that, once met, allowed the facility to achieve substantial increases in its Energy Star score. The Source EUI performance, and associated Greenhouse Gas emissions, could have improved, however, if incentivised directly. For example, these figures would be markedly better if the photovoltaic array installed on the building roof was used by the facility directly to reduce grid energy use, as proposed unsuccessfully as an innovation in Project Co’s original bid, but this would remove a separate revenue stream for the hospital.

As Project Co’s scope includes the management of all utilities at Facility 2, this includes water use. Although not a focus of this study, it is interesting to compare to energy use as conservation of water is not incentivised in the contract as done with energy (Withheld, 2010b). Figure 3 provides a summary of all water use at Facility 2 from 2014 to 2017 using a metric referred to as the Water Use Index with the unit m$^3$/m$^2$/year. As compared to the significant improvements in energy use, annual water use was highly variable over the period, with a possible upward trend ($m_{trendline, WUI} = 0.0218$). As with energy, in order to gain the facility’s LEED Gold certification the design and construction process involved various measures to reduce water use including installation of low flow fixtures and appliances, drought-tolerant plantings and a rainwater collection system. The difference is that no contractual Key Performance Indicators or incentives exist in the operations phase for Project Co to help the hospital conserve water. The unit and total cost of water at the facility are, however, about one tenth those of electricity and half those of Natural Gas, so it does not demand the same attention by the stakeholders.
Conclusion

This article introduces and analyses a healthcare corporation in Ontario, Canada with two large hospitals, one conventionally procured and maintained by hospital staff and one facility delivered as a P3. A retrospective, longitudinal case study using empirical data for specific FM processes - supported by facility user satisfaction surveys, interviews with key stakeholders and analysis of the P3 contract between Project Co and the hospital - provides an overview of their history, significance and specifications. Emphasis was placed on FM labour and energy use in the operations phase. This study’s findings show the P3 facility to have more efficient use of unionised FM labour and energy during the period surveyed, along with facility users that are more satisfied with the FM services. Though many problems existed at the P3 facility upon Substantial Completion, this is common at new facilities and longitudinal analyses of the energy and facility satisfaction metrics show an improving trend as the facility moved further into its operational phase. For energy use in particular, Facility 2 made dramatic progress in energy efficiency from a position of relative underperformance to Facility 1, relative to similarly classified facilities, to a position of significant outperformance. The positive, and generally improving, facility user satisfaction survey results through the operational phase at Facility 2 suggest that FM services are being performed effectively and that conditions are not degrading significantly.

Through the interviews, multiple possible reasons came up for the higher performance among the selected metrics for core FM services at Facility 2. Generally, Interviewee 2 (2017) summed it up saying, “There is definitely more rigor to adhering to [Key Performance Indicators]s at [Facility 2] than at [Facility 1] because we don't have to at [Facility 1].“ For labour use, the lower efficiency measured by both monthly WO events completed per unionised FM employee and IFS (m$^2$) per unionised FM employee, translates to the hospital’s ability to hold their internal staff to account. Though having installed a CMMS at Facility 1 to aid processing and trending of WOs, based on the positive experience at Facility 2, they stated that they would not be able to hold their own staff to the same expectations for response and rectification times. Contractually, poor maintenance performance is avoided at Facility 2 using a penalty-based approach in the contract, whereas high energy performance is incentivised using a Painshare/ Gainshare structure that compares actual electrical and Natural Gas consumption to energy targets provided by proponents at the time of bid and used in the selection of the winning team. These penalty and incentive mechanisms are unavailable for traditionally-procured facilities as the public owner takes on risk between contracts with the parties in the operating term unwilling to take the same risk of the Design-Builders’ performance. After poor energy performance in Facility 2’s first operational year, Project Co was assessed a large Painshare payment and thus implemented an extensive remediation programme to address deficiencies, thereby leading to a large Gainshare payment only two years later. This high performance is not matched by the facility’s water use for which, unlike
energy use, conservation is not incentivised in the contract. Interviewee 2 (2017) supported this saying they “get more and better information from the DBMF site” and that “sticking to [Key Performance Indicators] is better [at Facility 2] because it’s built into the contract”. Proponents also bid to those contractual conditions as they were provided in the RFP (Withheld, 2009). As observed by the installation of the CMMS system and application of facility user satisfaction surveys, it is common for the hospital to apply these best practices from Facility 2 to Facility 1.

The key findings from this case, which are likely to be replicated at other sites and therefore have broader implications for researchers and policy-makers, are: (1) the core FM processes included in this study suggest that FM resource use is more effective at the P3 facility, signalling that P3s are a more sustainable infrastructure delivery model; (2) there are benefits to having a diversity of facility delivery models within the same healthcare corporation as best practices can be transferred (at least partially) between facilities, such as the CMMS and facility user satisfaction surveys were in this case; and (3) there are also detriments to having both traditionally delivered and P3 facilities within the same healthcare corporation as, according to Interviewee 2 (2017), “At [Facility 1] my budget keeps getting reduced because we have budget constraints, while at [Facility 2] the budget keeps going up because of [Consumer Price Index] increases, so I almost have to try to take more out of other sites’ [budget] to accommodate for the lack of reduction in the building services side [at Facility 2]...every hospital [has reductions]”. The third point reflects an unsustainable situation of high importance to hospital decision-makers. As a result, despite the positive results at Facility 2, Interviewee 2 (2017) summarised this paper’s thesis in the following way, “the question really is, if the government or if the Ministry of Health had the funds available and didn’t have to go to an external developer to raise funds, would we still want to do a DBFM? Is it a truly better model for care? And “I don’t know”, is the answer.”

References
Canadian Green Building Council (2014) LEED Canada NC 1.0: Withheld. CaGBC.


**Appendix A: Interviews**

Recorded using Sony IC Recorder ICD-PX370 with manual transcription of points of interest.

Interviewees included:

1. Former Project Co Representative & Former Facility Management Committee Member. October 28, 2017. Duration: 60 min. Location: Interviewee’s home.
2. Former Hospital Representative & Current Facility Management Committee Member. Date: November 2, 2017. Duration: 70 min. Location: Conference room at P3 site
3. Hospital Project Manager. Date: March 20, 2018. Duration: 60 min. Location: Conference room at P3 site
Monitoring the built environment: Developing a dynamic tool to optimise renewable energy use and energy efficiency at a community scale using GIS

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Abstract: Within the framework of the well-recognised need for a more sustainable future, a number of ambitious targets and energy policies has been set, regarding CO₂ emissions and energy savings. As buildings are responsible for the 40% of the global energy consumption, it is crucial to optimise the contribution from renewable energy resources in the built environment, as well as to use the energy in the most efficient way. It is therefore necessary to enable the ability of in-depth monitoring in the built environment, at a larger scale than an individual building.

This study investigates the role that monitoring can play with regards to encouraging renewable energy use and optimising energy efficiency in the built environment, by developing a dynamic tool that can be used both at an individual building level and at community level.

A bottom-up methodology will be presented that incrementally aggregates buildings into a community level tool using a set of case studies. The number of buildings included within the tool will be gradually increased to collate information about a live monitoring experience of multiple buildings, located on different sites in South Wales.

Besides new ways to use monitoring in the context of sustainability, the conclusions of the study cover a variety of aspects related to the monitoring process, including choice of sensors and meters, data management (collection, transmission, storage and processing), availability by other stakeholders, choice of platform to manage the monitoring data, and cost-benefit analysis.

Keywords: retrofits, live building monitoring, community level, energy efficiency, renewable energy

Introduction

Energy use in built environment

Energy use in buildings is one of the most critical factors when aiming at mitigation of greenhouse gas emissions and global warming. 40% of the total energy consumption in European Union and approximately 36% of the greenhouse gas emissions are related to buildings (Departments of Business Energy & Industrial Strategy, 2017). The building sector is responsible for more than 40 percent of the European energy consumption but as stated in the IPCC WGIII Assessment report at the same time it offers the best technological opportunities to reduce energy consumption and greenhouse gas emissions.

The majority of the energy comes from fossil fuels, which leads to two major problems, the finite nature of fossil fuels and the air pollution caused from combustion, which is also related to climate change. A chain of impacts initiates from the energy consumption in built environment, which demands action in two general directions: Consume less energy and consume renewable energy as much as possible. In general, energy retrofits aim to improve the indoor environment, using less energy and renewable energy, and this study aim to quantify their efficiency.

Over 20 million houses exist in the UK and the annual replenishment rate is just 1%. Consequently, there is an increasing interest of the involved stakeholders on large scale retrofit programmes (Department of Energy and Climate Change, 2013). There is therefore a need for rapidly employed large scale retrofit programmes to take place which improve the housing stock, reduce emissions, create employment and improve quality of life and
occupants’ wellbeing whist being at an affordable level. Large scale retrofit programmes are planned and managed to be environmentally, economically and socially effective as possible.

In this context, an increasing attention has been drawn over the last decade, in building energy performance and its evaluation, specifically considering deeply retrofitted buildings (Turner & Frankel, 2008; Scofield, 2009; Fowler et al, 2010).

However, a “performance gap” is well recognised in relevant literature, indicating that retrofits as well as new buildings do not perform as expected. Dissatisfaction with the indoor air quality and with thermal comfort is common and the energy efficiency is not in the targeted level regardless of the new technology utilized and advanced systems installed (Menezes et al., 2012).

At present, however, technical systems in buildings are not usually monitored to confirm their performance or to check the energy efficiency of their operation. (Neumann and Jacob, 2008). Building performance is commonly specified and assessed in terms of desirable ranges of pertinent performance variables. Whereas building designs can be evaluated only based on virtual (e.g. simulation powered) monitoring of such variables, performance assessment of operating buildings should preferably rely on actual monitoring (Zach et al., 2014).

In this context, the need for large scale retrofit programmes is essential. Furthermore, there is a significant need to develop a systematic approach to evaluate the impact of the retrofit programmes. Aim of this paper is to introduce the concept of collating and visualising monitoring data from multiple buildings in a web-based platform. The scope of the present study is large scale domestic retrofit programmes.

**Monitoring is the basis for improving**

The famous quote from Lord Kelvin is more than valid when building performance is considered: “To monitor is to know. What can’t be measured can’t be improve either” (Wikiquote, 2018).

Here lies the importance of applying monitoring in large scale retrofits programmes.

To evaluate the actual outcome of a retrofit it is necessary to monitor the performance of the building both before and after the retrofit. To evaluate the performance of large scale retrofitting programmes, the methods used in individual buildings are no longer applicable and it is necessary to develop new tools, in order to collate and visualise the monitoring data, using a method applicable to a scale of hundreds of buildings.

The often significant discrepancy between the designed and real total energy use in buildings was recognized in IEA ECBCS Annex59-project “Total Energy Use in Buildings - Analysis and evaluation methods”. In the annex the following six factors influencing building energy consumption were defined (Figure 1): (1) climate, (2) building envelope (windows, wall, roofs, etc.), (3) energy-using equipment and systems (building services), (4) operation and maintenance of the building and its systems, (5) occupant behaviour and activity, and (6) requirements for the indoor environment.
According to the annex especially the latter three factors, related to human behaviour, can have an influence as great as or even greater than the former three. Therefore it is necessary to investigate all six factors together to understand building energy use data.

To monitor the energy use of one individual building, a monitoring system needs to be established. Besides energy meters and sensors used for data recording, a typical monitoring system should consist of data collection, data transfer and data processing (Figure 2). In the case of large scale monitoring, an additional step is to collate and visualise the monitoring data from multiple buildings.
2. Background

The collation of large scale monitoring data is not common in literature. Only two relevant case studies were identified in literature, where large scale monitoring data were collated in one web-based platform. In both cases this platform is a Geographical Information System (GIS) based platform.

In the first case study, a GIS platform was used as support tool for developing a sustainable energy action plan in the municipality of Randazzo, which is situated at the northern foot of Volcano Etna (37°52′37″56 N; 14°57′1″80 E; altitude 765 m), 70 kilometers northwest of Catania (Gagliano, 2015).

The Randazzo study aimed to help local communities to make decisions for estimating and monitoring the energy consumption in buildings (residential, commercial, industrial), and to simulate effects of energy policies (the process is shown in Figure 3). The implementation of GIS platform was essentially used to give a mapping representation of the actual state of energy resources and demand, to develop sustainable energy policies. Large scale energy consumption data from multiple buildings is collated in a GIS database and is linked with the buildings’ characteristic. Although, the energy consumption of the Randazzo municipality was calculated, using historical data from databases: the Regional Informative System for Environment and Energy, and the National Census database year 2001, 2006, and 2012 (Gagliano, 2015). Therefore, in the Randazzo study energy consumption data was provided by modelling and calculations, rather than monitoring. The scope of the Randazzo study includes mapping data from all kinds of buildings in the municipality. The aim of the Randazzo study is to use mapping representation in a GIS platform to develop sustainable policies.

The Randazzo study concludes that the adoption of a GIS-based platform proved to be a suitable support tool during the phase of elaboration of a Sustainable Energy Action Plan, as well as during the phase of realization. A further conclusion of the same study is that it is possible to propose such methodology for application in different geographical areas or context, such as to support energy policies at the urban level, or to make decisions for estimating and monitoring the energy consumption in residential, commercial or industrial buildings (Gagliano, 2015). Therefore, even if the Randazzo study is not focused on monitoring energy consumption, it concludes that GIS platform is suitable for collate and visualising energy consumption monitored data.

The second project that uses GIS platform to collate and visualise monitoring data, is U-eco-city in Korea. U-Eco City is a research and development project initiated by the Korean government in 2008 (Shin, 2010). The project’s objective is the monitoring and visualization of aggregated and real time states of various energy usages represented by location-based sensor data accrued from city to building scale. The system is not only used by energy management specialists but also by the general energy consumer.

In this context, a prototype energy monitoring system called EnerGIS was presented. It is a Web-based rich-internet application (RIA) integrating a 3D geospatial viewer based on the Google Earth platform and Google Maps components with additional data visualization modules. Combining city information model data from the database, power sensor data through sensor network, and environmental GIS data, it builds up its own monitoring database.
The main characteristics of the Korean project are:
- Web based platform
- Intuitive statistical data visualization
- Real-time based sensor data collection and data optimization
- Dynamic data loading and visualization
- Extensible city information

The research objectives:
- Optimized data structure model of urban environment
- Data optimization for 3D city representation
- Visualization strategy

This paper summarizes the gains from designing the database structure to enhance system performance and to implement a customized middleware engine to optimize the visualization method, which is mainly based on a Level of Details strategy. In this process, significant knowledge was acquired for databases that manage large amounts of data that are continuously aggregated by time flow, and for a system architecture that represents an energy driven urban environment. Furthermore, the know-how for a web based management system was developed, which delivers sensor data, statistical data mining and diverse information visualization.
3. Methodology

A bottom-up methodology from one individual building to large scale

The proposed concept is to collate and visualise monitoring data from multiple retrofits in one single GIS-based platform using bottom-up approach. The case study of one individual dwelling (case study one) is used as a pilot case to define the framework for a replicable process, gradually adding monitoring data from multiple buildings into a single GIS-based platform.

The advantage of this accumulative approach is that different challenges will be revealed at each step of the upscaling and more easily solved due to gradually increasing the number of buildings.

Case study one will give a clear picture for the potential effectiveness and applicability of collating and visualising monitoring data into one platform, and the challenges related within each different scale of the process, while preparing the framework for future work.

Case study one

Case study one is a dwelling which was retrofitted as part of the SPECIFIC 2 LCBE Project, led by WSA at Cardiff University. This is a pre-1919, solid wall, end of a terrace house, which is owned by a social housing company, located in South Wales (Figure 4). The house was chosen as its layout is representative of the existing building stock in Wales, it has two storeys with a footprint of 36 m² (total floor area of 72 m²). The living room and kitchen are on the ground floor with two bedrooms and bathroom on the first floor. The house has a garden accessed from the rear façade plus a side gate from the street (Figure 4).

As part of the SPECIFIC 2 LCBE Project, a semi-structured interview evaluating occupant behaviour and appliance and lighting use was carried out to assess the building performance before the retrofit. Geometric dimensions are presented in Figure 5 and properties of the building fabric are presented in Table 1.

![Figure 4 – Building envelope (SPECIFIC 2 LCBE Project)](image)

![Figure 5 – Building’s layout (SPECIFIC 2 LCBE Project)](image)
<table>
<thead>
<tr>
<th>Element</th>
<th>Measured U-value (W/m²K)*</th>
<th>Estimated U-value (W/m²K)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall, East (50cm non-insulated solid wall + Spa dash)</td>
<td>1.45</td>
<td>-</td>
</tr>
<tr>
<td>External wall, West (50cm non-insulated solid wall)</td>
<td>1.50</td>
<td>-</td>
</tr>
<tr>
<td>External wall, South (70cm non-insulated solid wall + Spa dash)</td>
<td>1.30</td>
<td>-</td>
</tr>
<tr>
<td>Party wall, North (50cm non-insulated solid wall)</td>
<td>-</td>
<td>1.50</td>
</tr>
<tr>
<td>Loft</td>
<td>-</td>
<td>0.25</td>
</tr>
<tr>
<td>Ground floor</td>
<td>-</td>
<td>2.70</td>
</tr>
<tr>
<td>Window</td>
<td>-</td>
<td>2.20</td>
</tr>
<tr>
<td>Door</td>
<td>-</td>
<td>2.20</td>
</tr>
</tbody>
</table>

Table 1. Thermal properties of the building. (SPECIFIC 2 LCBE Project)
*Based on survey of property.
**Based on Energy Performance Certificate (EPC) data.

The building has a wet heating system fuelled by a gas combi boiler. Heating is set by occupants at 19°C which is boosted up to +30°C at times. Both the ground and the first floors are heated, the loft space is unheated. The Domestic Hot Water (DHW) is heated instantly by the combi gas boiler, which has a measured efficiency of 80%, the shower is electric. To ventilate the house, occupants use natural ventilation, controlling the opening of windows and trickle vents.

The retrofit which took place as part of the SPECIFIC 2 LCBE Project, included fitting internal and external wall insulation, TSC and MVHR installation, solar panels and battery installation.

**Data collection**

This paper will focus on the use monitoring data to be included in the web-based platform, an optimisation is needed to ensure two criteria: a) the monitoring data will be sufficient to lead to meaningful results, and b) the amount of data remains at a manageable level. Further data which add complexity to the system, without equally contributing to the results, are to be avoided.

The aim of the monitoring defines what data is meaningful. For the purpose of evaluating a retrofit it is essential to measure the building performance before and after the retrofit. To evaluate the building performance the following information is necessary:

Fabric: To evaluate the financial and environmental impact of fabric improvement, energy consumption is correlated with the U-values of the buildings. This data can help to compare between well and not insulated buildings, to quantify the impact of insulating interventions, and reveal performance problems in certain buildings. The size and the type of the building are also important for this evaluation. That type of data is characterized as static, since it remains unchanged with time. Regarding the case study one, this information is extracted from the survey, measurements and EPC data.

Energy consumption: Electricity and gas consumption are monitored. Majority of dwellings are connected in electricity and gas grid (Energy Consumption in the UK, 2017).
Regarding gas, which can be further broken down in heating space, heating domestic hot water (DHW), cooking and in some cases other appliances using gas as fuel. According to literature (Energy Consumption in the UK, 2017) energy consumption for heating space is the dominant factor (56%), second is domestic hot water (22%) and last is cooking with only 6%. Total gas consumption is sufficient for the comparative study before and after the retrofit. In the case of electricity, besides electricity consumption, there is electricity generation, as renewable energy systems installation is a common practice in retrofits. In order to simplify the system, total energy consumption may be used, without sub-metering. According to ASHRAE 14-2002 Guideline for measuring of energy and demand savings, 15-min interval is suggested to measure both the gas and electricity consumption.

Regarding case study one, gas and electricity consumption data is monitored using the monitoring system installed within the SPECIFIC 2 LCBE Project.

Environmental data: To evaluate the energy performance of a building, the energy consumption needs to be correlated with the indoor and outdoor environmental data. Representative aspects to describe thermal conditions are temperature and relative humidity. Solar irradiation, wind speed and wind direction are significant environmental data, but for simplifying the process those environmental data are not implemented into the platform, as the complexity added would be more than the contribution.

Regarding outdoors temperature and relative humidity, one option is to install a weather station (or a simplified form of one outdoor temperature/humidity probe) outside every building, and the second choice is to take outdoor data from the nearest available weather station. Regarding case study one, installing a probe in the building is feasible, but eventually, when applied in hundreds of buildings this will not be feasible. In that case, one weather may be installed for every neighbourhood, or data may be obtained from a local weather station, in case there is one.

Regarding indoor temperature and relative humidity, major spaces that are common in all houses are the bedrooms, living room, kitchen and bathroom. To simplify the system, one value per house is used as an indication of the indoor temperature and relative humidity. As a representative space is chosen the living room, as it is the most demanding space of the house regarding thermal comfort (CIBSE guide).

People: The number of residents is affecting the energy consumption, as the needs for space heating and for hot water are directly related with the number of residents. Occupancy related data can be altered without following a specific pattern. Regarding the case study one the information about the initial occupancy status is extracted from the survey contacted by the SPECIFIC 2 LCBE Project. Surveying at predefined times may be used to update the number of residents in future.

4. Results

This paper introduces the concept of collating the monitoring data from multiple building in one web-based platform. Case study one has resulted in a clearer picture of the needs for collating and visualising from multiple buildings, which are presented below as a series of steps:

The process from data recording to data visualisation

Step 1: Data recording

Data recording takes place exactly the same way as it would have been for monitoring one individual building. Gas and electricity meters were installed to measure gas and
electricity consumption respectively, whilst a temperature/relative humidity sensor was placed in the living room and a temperature/relative humidity probe was placed outside the house. A PV system is installed on the roof of the dwelling, so an additional electricity meter was installed to monitor the generated electricity.

**Step 2: Data transfer**

As the main objective of this replicable process is to collate data from a large number of buildings, a manual method of data collection and transfer would not be efficient. An automated and remote method of collection and transfer is needed, to facilitate data transfer from a large number of buildings and from multiple sites. A web-based data transfer method is chosen, to ensure a remote and automated process. To enable the remote data transfer, the monitoring data needs to be collected and locally stored in a data logger. A data logger is installed in the dwelling and programmed to collect the monitoring data and to transfer it to a web-based platform. An internet connection is ensured to connect the local data logger with the web-based platform.

**Step 3: Data pre-processing**

The monitoring data is being collected and transferred as raw data. The format of the raw data depends on the type of the sensor, most likely a csv or an excel file. A pre-processing stage is needed to convert the raw data into a suitable for further processing format. Firstly, the file is to be converted to an excel spreadsheet in case it is generated as one, as this format is easily manageable for further processing. Secondly, certain calculations may be needed to convert raw data into meaningful information. For example, in case of measuring gas consumption with a pulse meter, the raw data is counts of pulses which is transformed to consumption units using simple functions.

In the case of one individual building this process is manually preformed, but this method is not efficient for managing monitoring data at large scale. This point is one of the technical challenges to be met.

**Step 4: Data processing**

The final step is to collate the monitoring data from multiple buildings in the same web-based platform. Processing the data may include different tasks depending on users questions, may be creating combined charts to compare different buildings, collating buildings with similar characteristics, creating daily profiles with regards to the time.

**Step 5: Data visualising**

Visualisation may vary depending on the objectives, might be a chart, a bar chart, or a coloured map to represent consumption level.

**Classification of the challenges**

**Technical challenges.**

The main challenge revealed is the need to automatically manage the monitoring data, at the pre-processing and processing stage. According to relevant literature (Shin, 2010) this challenge may be addressed by developing a middleware, a specialised software to facilitate the pre-processing data to implement it in a database.

An automated processing of the data is needed, after the implementation in the platform. Depending on the kind of data a different process is needed, to visualise the variation of a data set or the comparison between different datasets. The platform needs to provide the adequate visualisation techniques, to transform datasets into a graph or a bar chart. A necessary feature of the web-based platform is the flexibility to change the grouping
of sites and the choice of data on demand. The adequate platform should provide the flexibility to investigate a variety of questions, by easily grouping different buildings based on their characteristics.

Financial challenges.

The development of a monitoring system includes the installation of the sensors as well as the equipment for data collection, for local data storage and for data transfer. The choice to monitor a large number of buildings instead of choosing individual case studies multiplies the number of monitoring systems to be installed. That causes a considerable cost, regarding equipment (mainly sensors and data loggers), as well as specialised personnel for the installation.

The process of upscaling is designed to upscale gradually, by doubling the number of buildings at each stage. The process of upscaling will be beneficial up to a certain extent, due to a certain extent. Beyond that extent the benefits will not be able to justify the additional cost. A cost-benefit analysis for each stage of upscaling is needed to quantify that extent. This can be investigated as part of future work.

An alternative solution to this challenge, is installing smart meters within the retrofitting programme. Smart meters collect and transfer the energy consumption data in a digital form, which reduces the cost, as there is no need for installing meters and a data collection/transfer system. In this case, an alternative solution regarding environmental data is needed. Weather stations may be installed for each neighbourhood, or data from existing weather station may be retrieved. Regarding the indoor temperature, the set point may be used as an indication, or smart meters with integrated sensor may be chosen.

Social / legal challenges.

A significant challenge that may arise, regarding privacy issues related with the energy data. Energy consumption data may be used for commercial purposes, it is considered as private data and the right to this data is legally protected. The consent of the tenants is necessary to use this data for research or energy management purposes.

A related challenge is that in the case of smart meters and PV installations the data is managed by companies. Suppliers or renewable installers may deny to share data.

5. Conclusions

The value of collating and visualising different types of related data

The value of collating different types of monitoring data (energy consumption, fabric, environmental, people) from multiple buildings is justified by the following benefits.

Firstly, the actual outcome of a retrofit programme will be validated. The impact of large scale retrofit programmes is essential to reduce energy consumption and carbon emissions in the built environment, but also a further effort is needed in order to verify that the outcome is close to the ideal (Newsham et al, 2009). The lack of this further effort might cause a significant ‘credibility gap’, as monitoring and assessing buildings post occupancy performance after the initial design and construction is not the common practice. Without this feedback, the actual efficiency of each intervention remains invalidated, a successful one would not stand out or an unsuccessful one might be repeated (Bordass et al., 2004).

Secondly, different types of monitoring data will be correlated in a holistic analysis. Literature shows that the actual result of the energy performance of a building is not matching the ideally expected one, as it was calculated through the design and the modelling process (Darby, 2008; Menezes et al., 2012). The combined study of all the related factors is aspired
to shed light to this performance gap between the expected and the actual outcome. In addition, large scale monitoring data will contribute to further optimisation of the modelling process for planning future retrofit programmes.

Thirdly, the holistic analysis may contribute to the quantification of the social aspect of the retrofits. A main driver for retrofits is to fight fuel poverty and improve the indoor environment, including thermal comfort, air quality and lighting. This is a very important aspect of the retrofit, which may be indirectly evaluated, by relating the energy consumption with the indoor conditions before and after the retrofit.

Finally, collating monitoring data from multiply houses, eventually structures a network between houses at community level. In this network essential information is gathered, such as real-time data about energy usage and generation, related with the spatial and temporal factor. That infrastructure may have a major contribution to the recent discussion about the decentralisation of the energy system (van der Schoor et al., 2016). Based on this network, the applications may extend from monitoring to energy management at community level. Moreover, new potentials can be explored such as community shared renewables and energy storage units (van der Stelt et al., 2018).

6. Discussion and future work

The potential users

The significance of the proposed concept is evaluated with regards to the potential users. Moreover, the way forward to future work is depending on the potential users, as the focus of future work is depending on the type of potential users:

1. Public authorities or institutes, that implement large scale retrofitting programmes at municipal, regional or even national level. In this case the focus will be on evaluating the effectiveness of a programme and collecting data for future planning.

2. Energy suppliers and energy management companies. Real time monitoring of energy data related with spatiotemporal aspects may help balancing the network at community level. Real time monitoring may also contribute to dynamical tariffing system, based on the local demand and supply. Energy managements companies may implement community based approaches or social enterprises may take action in energy management at a local level. In this case, the focus will be on real-time data and balancing between energy production and demand at community level.

3. The tenants themselves may be the end users. In combination with dynamic tariffing system or local energy management, a user friendly application may inform the tenant about the energy consumption, the efficiency, the indoor/outdoor temperature and to suggest potential ways to reduce the bills and to optimise the energy usage. In this case, the focus will be on the end user.

The GIS-based platform

Future study aims to investigate the use a Geographical Information System (GIS) platform to collate and visualise the monitoring data, as it appears to have a number of benefits. In the last years, many studies have used GIS platforms for energy and environmental prediction models. In addition to facilitating a realistic representation, GIS provides an adequate platform for multilayer analysis. Further, the GIS platform has been valued for improving communication and collaboration in decision making, for effectively managing resources and improving the accessibility of information. Further, spatial mapping enables implementing more features in the platform, such as renewable sources or energy storage units. Therefore,
GIS is recognised to be able to play a significant role as a platform for systematic approaches, integrating energy models and interactively linking them to real-world data (Gagliano et al, 2015).

A further benefit is that relating the data with the spatial aspect multiplies the potential for further analysis. Special areas of interest can be isolated and studied in detail. Space geomorphology may be related to environmental factors or influence the expected efficiency of the intervention. Fuel poverty issues may be analysed with regards to geosocial distribution of the population. Post occupancy studies may relate certain behaviour with spatial aspect. Many more spatial correlations with energy related data may arise depending on different approaches.

Acknowledgements

The presented case study is part of the SPECIFIC 2 LCBE Project. SPECIFIC 2 LCBE Project is part-funded by the European Regional Development Fund (ERDF) through the Welsh Government, and also by Innovate UK and the Engineering and Physical Sciences Research Council (EPSRC).

The authors would like to acknowledge all the team members of the SPECIFIC 2 LCBE Project, as well as the Wales & West Housing Association, for the work in the design and installation stages of the case study.

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An optimisation design framework for residential buildings integrating air-source heat pump multi-supply system, active thermal storage, and onsite renewable energy

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Abstract: Domestic heating, cooling and hot water take a large proportion of total energy consumption in residential buildings, and contribute significantly to the greenhouse gas emissions, because the energy used is mainly from fossil fuels. Electrification of these three systems combined through an air-source heat pump (ASHP), and then decarbonisation the electricity by building integrated renewable power generation, will help to significantly reduce carbon dioxide emissions. Moreover, using building envelopes as active thermal storage by embedding the water loops of ASHP air-to-water system, can make the capital cost of the holistic system very competitive in comparison with conventional systems. Furthermore, such system can shift domestic energy consumption from peak usage period to local renewable generation’s peak output period, whilst still providing the needed comfort in time. Thus, the grid is less interrupted, and the occupants can have better financial benefits without compromising comfort needs. Such integrated and holistic system has large potential to play an important role in carbon reductions in the future housing sector. However, designing such system can be complicated and needs new approach to coordinate the stakeholders’ works. This paper uses a case study to present an optimised design framework for demand, storage and renewable generation integration through such ‘ASHP multi-supply system+ thermally activated building + onsite renewable generation’ strategy, which helps future practice to design such systems properly and cost effectively. And the discussions in this paper about design issues will enable future improvements of component design and system efficiency.

Key words: Air-source heat pump, Multi-supply system, Thermally activated building, Renewable electricity, Holistic integration

1 Introduction

Residential energy consumption takes about 14% of the total energy consumption in the UK (13% in China), and this energy is mainly supplied by natural gas in the UK (biomass, coal and peat in China), among which 82% are consumed by heating, cooling and domestic hot water in the UK (65% in China) (NHBC Foundation, 2011). Therefore, there is large need and potential to reduce residential sector’s environmental impact through energy conservation and decarbonisation in these three areas.

Previously, demand side reductions have been mostly emphasised, and the construction industry responded positively by enhancing air tightness and envelope insulation. However, the cost of construction has increased correspondingly, which indicates that demand side reduction would only reach certain level, and then be restrained by housing affordability issues in practice. Therefore, decarbonisation on the supply side becomes essential to further reduce the carbon emissions in housing sector, and energy storage starts to play an important role to extend the application of renewable energy generated on site.

In 2015, the first affordable energy positive house, SOLCER House, has been launched as a demonstration that tough low carbon targets can be achieved by affordable and available solutions in the market through whole house integration. This house uses a holistic approach to integrate demand, storage and supply at the same time, which significantly reduces the capital cost of the house to local affordable level (£1000/m² against local social house £800-1000/m²). Moreover, it uses heat pump air-to-air system with heat recovery in ventilation and hot water tank to satisfy heating, cooling and domestic hot water needs in one go. It also installs a 4.3kWp PV as the roof, which can directly drive the heat pump system at the peak
generation time. Such holistic system design achieves a 1.75 grid export-to-input energy ratio with 70% autonomous energy rate, and significantly reduces the operational carbon emissions (Jones P. et al, 2016).

SOLCER House’s experience addresses that simultaneous design at early stage is essential to ensure the success of installing highly integrated systems, and a design framework is needed by all the stakeholders, to organise different specialists’ work and set up the feedback mechanism with decision making criteria. Or else, technically sound strategies may not achieve its maximal cost reduction potential, and the fundamental reasons for some decision makings may be lost in the long construction process, which makes the design strategies not implemented consistently and properly.

Therefore, summarising the experience gained in the SOLCER House project, this paper uses a real project case study in China to explain how an optimised design framework could help in performance optimisation and cost reductions, through bringing architects, engineers and other stakeholders to work as a coordinated team to deliver a ‘logistically complicated, but practically simple’ system. It also demonstrates the flexibility and adaptiveness of such optimised design framework - although both cases use ASHP system to deal with heating, cooling and hot water in one go, the case in China develops totally different combination of technologies, because of different climate, site conditions, locally available products, lifestyle and feed-in-tariff policies. However, the core principle of ‘demand, storage and supply integration’ is still maintained through following the guidance of the design framework.

2 Design framework description

There are many types of framework to explain or organise low carbon housing design, each of which has its own focus and priority. For example, Dunsdon et. al. (2006) once summarised a computer-based framework which addresses the fact that low carbon designs are highly simulation assisted, therefore, need a framework to work with the computational process. Baba (2013) further investigated the practices in the UK and suggested that ‘there is need for new generation of tools, by which early design decisions, especially ones at the conceptual stage, must be adequately informed’.

However, one of the most challenging aspects of simultaneous designs for low carbon residential buildings, which involves multi-discipline simulation, is that they are highly unstructured in the practice. To integrate demand, storage and supply, the traditional ‘architect led’ design process is no longer effective enough, because there are many areas in which architects do not have the knowledge to merge the designs together as an integrated ‘product’. Thus, the design frameworks suggested by Dunsdon and Baba, which are based on traditional architects led ‘design-and-build’ process, are not sufficient to guide the highly interactive system described in this paper.

Attia et. al. (2012) looked at the same problems from a different angle: rather than following the traditional design process and seeing where simulation tools could fit in to do analysis, they divided the whole design process into ‘modules’ (Climate, Orientation, Geometry, Envelope, Systems and Active Solar, Figure 1). Then, they linked the information flow among the features to the inputs and outputs of a simulation tool, so ‘it can become an immediate yet comprehensive support to make informed design decisions’. Such way of thinking treats a building design process as an integrated unit with modular input information and predefined output data to be analysed. This research inspired the optimised framework in this paper (Figure 2), which divides the whole integrated system into modules, and groups certain modules together with a shared feature (Design conditions, Technologies, Integrated
Components, Services, Medium, Functional space, and Occupants’ need, Figure 2) in the design process. The difference is that the framework formulated in this paper is not restrained by a specific simulation tool.

Figure 1. The flowchart of ZEBO energy simulation tool Attia et. al. (2012)

Figure 2. Design framework for building integrated holistic supply, storage and demand systems
The advantages of the optimised design framework in this paper, comparing with those previously discussed, are: 1) it can be adopted at any design stage for both new build or retrofitting projects, because there is no specific order to be followed in the framework; 2) it does not rely on any particular specialist to lead the design process, because all the relevant professional work has been divided into modules of the holistic building product, and the interactions among different modules can be easily found as well as further explored; 3) it does not follow any specific procedure of design or simulation tool, so will not be restrained by any algorithm or special knowledge/skills.

3 Application of the design framework in China

In the past five years, utilising the renewable electricity generated on site and shifting electric load from on-peak to off-peak hours by local storage, has become a multi-benefit strategy which reduces CO\(_2\) emissions, enhances grid safety, and brings economic gains to residents (Arteconi et al, 2013; Liu et al, 2017; Zhang et al, 2017). To implement such strategy, ASHP air-to-water system has an advantage over air-to-air system, because its heat media – water – has higher thermal capacity, in that case it can store more heat in the media and hold it for longer use in the end plant. Furthermore, they can be embedded with building envelopes to extend the storage capacity, which makes the buildings thermally active. Such Thermally Activated Building Systems (TABS) have been proved to be energy efficient, grid friendly, cost effective and thermally comfortable (Park et al, 2014; Schmelas et al, 2017; Shen & Li, 2016; 2017; Xu et al, 2017).

However, the previous studies on the TABS were more from the heat transfer and envelope’s heat storage capability point of view (Ma et al, 2015; Navarro et al, 2016), and the rare cases on investigating the applications of ‘HPs + TABS’ in residential buildings either do not see onsite renewable electricity generation as a cost effective way of CO\(_2\) emissions reduction (Xu et al, 2010), or the capital cost saving potential is not investigated as thoroughly as operational cost savings (Romání et al, 2018; Romero Rodríguez et al, 2018). As Navarro et al stated (2016) ‘Although current TES (Thermal Energy Storage) technologies developed by researchers demonstrate significant potential, there is a lack of knowledge concerning their functional and architectural building integration.’

Despite the limited existing research on the ‘ASHP multi-supply system + TABS + onsite renewable electricity’ integration, the local practice in China has adopted such strategy in practice. And the case study below explains how the design framework presented in this paper helps to optimise its predicted performance through simulation assisted design.

4 Case study – Domestic Dwellings in Xi’an, China

4.1 Background

The project is located in Xi’an, China, a city which has cold winter and hot summer. The site is near to the Chanba National Wetland Park, therefore, benefits from the good local microclimate and is suitable for many passive design strategies. It has good access to wind and solar resources, because there are no surrounding high-rise buildings, instead, there is large open space towards a main road near a river bank on the south of the site (Figure 3).

The mid-terraced house in the most southerly row (highlighted in red in Figure 3) adopted the SOLCER House’s concept of ‘demand, storage and supply integration’. Before simulation can be used to optimise the HVAC systems, thermal storage and onsite renewable energy generation, the planning permit was issued based on conceptual architectural design.
This prohibits any alteration to the house’s orientation, form, shape, height, and external layout.

Initial weather data analysis indicates that the conceptual architectural design made appropriate choices on orientation, shape and external layout, so the demand side load control will be focused on the insulation level and the window-to-wall ratio of the facades.

Figure 3. Site map and external layout

The weather data analysis also shows that the local site is suitable for PV and solar thermal installation, but the general wind resource is not ideal, so the decision to install a micro wind turbine will be reviewed when demand side data is finalised. The local feed-in-tariff rate is summarised in Table 1, and based on the policy, it is decided that the design criteria for renewable energy generation system is ‘self-use mainly + export to grid if left over’.

Table 1. Feed-in-tariff of renewable electricity in Xi’an (Unit: Yuan RMB)

<table>
<thead>
<tr>
<th>Feed-in-tariff policy</th>
<th>Self-use</th>
<th>Export to grid if left over</th>
<th>Totally export</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic cost saving</td>
<td>0.4983 for the first 180 kWh per month, 0.5483 for the 181 – 350 kWh per month, and 0.7483 for 351 and above</td>
<td>0.3346</td>
<td>0</td>
</tr>
<tr>
<td>Feed-in-tariff</td>
<td>0.42</td>
<td>0.42</td>
<td>0.85</td>
</tr>
<tr>
<td>Total cost benefit</td>
<td>0.9183 – 1.1683</td>
<td>0.7546</td>
<td>0.85</td>
</tr>
</tbody>
</table>

As a commercial product, no matter how brilliant its functions would be, the capital cost must be competitive to the existing products in the market, and the supply chain for its elements must be stable. For these reasons, the developer sets some caps to the foreseeable increasing costs, as well as procurement conditions.

All the above background has been reviewed through the ‘Design conditions’ layer in the design framework, and the decision-making criteria has also been summarised in Table 2 for the ‘Technologies’ layer.

Table 2. Decision-making prioritisation for choosing and designing technologies

<table>
<thead>
<tr>
<th>Method</th>
<th>Onsite energy supply</th>
<th>Onsite energy distributions</th>
<th>Onsite energy storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onsite energy supply</td>
<td>PVs are definitely included because of subsidies.</td>
<td>ASHP for heating, cooling and hot water, Others depend on customers’ need</td>
<td>Thermally activated building Hot water tank. No requirement for electricity storage: excess to grid</td>
</tr>
<tr>
<td>Onsite energy distributions</td>
<td>Solar thermal inclusion depends on available roof.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onsite energy storage</td>
<td>Micro wind turbine to be explored on its payback time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System connections</td>
<td>Grid connected. Mainly self-use, export excess to grid.</td>
<td>Electricity either from local generation or grid. Aim to maximise the local generation usage.</td>
<td>ASHP water loops embedded with building fabric. Hot water tank as an energy sink of solar thermal and ASHP system.</td>
</tr>
<tr>
<td>System connections</td>
<td>Maximise autonomous energy rate.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Tender cost** should be based on a holistic package of ‘supply system’ rather than each element, and the system should not be more expensive than the ordinary costs if purchasing the elements separately. The whole system should aim to have similar cost as the ‘boiler + air conditioning’ strategy. If the system is more expensive due to limited choices in the market, savings should come from smaller sizing due to better design. Should not be extra cost besides the ‘material consumptions’, and the installation should not further delay the onsite construction process.

**Procurement** Better to be locally available, if not, orders should be delivered before scheduled installation time. If there must be some adjustments of standard market products, the ‘special order’ fee should not exceed 20% of the market price.

**4.2 Simulation assisted design process and the use of the design framework**

**4.2.1 Clarify the interactions between technologies using the design framework**

For traditional housing project, detailed system design is always after architectural design, and M&E engineers just need to locate the plants in the places ‘given’ by architects, and size the system to the load ‘predefined’ by architects. Such process is certainly not suitable to thermally activated building systems when the envelopes are part of the HVAC systems.

![Occupied design framework created in the studied case](image)

Therefore, as soon as the conceptual design has made choices on building forms and systems, it is essential to locate each HVAC system element into the design framework, and establish...
the inter-relationships, so that the designs of key components can be highlighted and coordinated from the beginning.

The adjusted design framework for the studied project at the conceptual design stage is shown in Figure 4. The main issues and relevant fundamental decisions made at early stage are:

- Walls are not to be used for embedding water loops because
  1) they will reduce the usable space significantly, which reduces the value of ‘building product’ in the market
  2) the available external wall areas are very limited and hard to locate the water loops due to the building form

- Suspending ceilings of water loops are not applicable because
  1) the planning permit has defined the building height (in total and for each floor), so under floor heating + suspending ceiling cooling will make the net height of each floor less than 2.6m, which goes below the minimal requirement
  2) the developer does not accept the increased cost brought by suspending ceiling, therefore, only floors are the applicable places for embedding the loops

- Pitched roof is rejected because
  1) The initial calculation shows that the total height of the building with pitch roof will go beyond the requirement of planning permit
  2) It will block the view of second row of buildings towards the river bank

- PVs and/or micro wind turbines are only installed on the roof because
  1) the stand-alone installations (such as PV-turbine hybrid courtyard light) need expensive mounting kits to get a limited increase in generation
  2) the engineers have concerns on health and safety issues from operation point of view, and the developer has concerns from the management point of view

- MVHR (mechanical ventilation heat recovery) with air purification is included because Xi’an has experienced heavy air pollutions recently. There is also concern about indoor air quality, due to air pollutants widely contained in the interior decoration materials available locally.

- Solar thermal is excluded because initial calculation shows that the required PV generation would occupy the whole roof and has been prioritised above solar thermal

- External wall cannot be further insulated to a better level, because it needs to keep consistency with other neighbour terraced house, and the developer does not want to increase other houses’ insulation to match this demonstration one.

4.2.2 Modelling tool
There are wide ranges of modelling tools freely available or purchasable. They could be as simple as spreadsheet, or so complex they need special knowledge to operate. However, the required knowledge and skills to complete calculations for this design framework are commonly available in any country. Each simulation methodology and tool may have its own advantages and limitations, but through following this optimised design framework the same conclusions should be drawn. However, it is important to recognise that steady-state heat transfer methods are not suitable for this framework, because they cannot deal with the
hourly and seasonal variation of demand side loads to guide the sizing and integration of thermal storage and renewable electricity generation.

HTB2 (Heat Transfer in Buildings version 2) was used in the SOLCER House project, and adopted in this case study, to investigate the demand side load variations. The biggest advantage of this tool is that it is ‘...a flexible tool for studying the detailed operation of a building on a short time scale, of minutes rather than hours...’ (Alexander, 1996). However, other tools such as DesignBuilder (with EnergyPlus as the calculation engine), IES-VE, DOE-2, ESP-r, eQUEST, TRNSYS etc, would be equally suitable.

4.2.3 Design process and simulation outcomes

Demand reduction
No matter what design strategies are taken, the most important part of low carbon design is always to reduce the energy demand. In this project, natural cross ventilation and sufficient daylight have been optimised through architectural design of building form in early stage, and it has been a common knowledge that air-tightness is essential to the success of low temperature radiant heating. According to the local design code for energy conservation, the indoor design temperature is a minimum of 16 °C in the winter and a maximum of 27.5 °C in the summer for the whole house radiant heat transfer strategy. In that case, the main tasks for simulation are to optimise the window-to-wall ratio and insulation level, in order to balance the heating and the cooling load. This means that the simulation exploration only needs to focus on ground and roof insulation.

The order of simulation tests in this case study is to:
1) calculate the optimal window to wall ratio under natural ventilation mode
2) calculate the optimal ground/roof insulation level under natural ventilation mode with optimised 1) result
3) establish the start and end of heating / cooling season under natural ventilation mode with optimised 1)+2) results
4) calculate the needed capacity of radiant surface (floor and ceiling area + embedded water loop density + supply/return water temperature) under natural ventilation mode, and design the operation schedule for ASHP system accordingly
5) further explore the needed capacity of radiant surface under MVHR mode, and design the operation schedule for ASHP system and MVHR cooperatively
6) validate the capacity and operation schedule of HVAC systems by comfort and health requirement (indoor air temperature during occupied time and condensation potentials in the cooling season)
7) finalise the optimised strategy to achieve optimal energy performance

It should be noted that a basic occupational schedule needs to be assumed before the simulation tests start, and this largely depends on the lifestyle of the occupants. Thus, the ‘optimised strategy’ concluded from above procedure is only for the assumed occupancy style, if the residential building is designed for flexible family structure or wide ranges of distinctive lifestyles, the above procedures must be repeated for each typical occupancy style to explore the similarities and differences, before finalising a ‘general’ optimal strategy.

Generation optimisation
With the given roof area and installation specifications, the supplier of PV-wind turbine hybrid generation system proposed two strategies (Table 3). Strategy A is more economical from traditional calculation point of view, because it has less capital cost and shorter pay back period. However, strategy B is chosen because: 1) it has higher peak power capacity, which
makes it possible to directly drive the heat pump system in off-peak usage time (peak generation time), and store the heat/coolth in the floors for later use, which largely increases the self-used electricity percentage for increased income to occupants under local feed-in-tariff policy; and 2) such capacity significantly reduces the whole house’s dependency on the grid, which especially benefits the grid in the summer by smoothing the electricity usage curve and shifting some load to off-peak time, or else, the domestic heating/cooling and hot water load will be added up together by the ASHP multi-supply system in the evenings.

### Table 3. Comparison of two generation strategies*

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Way of installation</th>
<th>Capacity</th>
<th>Annual predicted power generation</th>
<th>25 years total income based on 50% self-usage + 50% export assumption under current feed-in-tariff policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A South orientation, 26° tilted</td>
<td>3.84kWp PV+1.5kW Turbine</td>
<td>PV: 4673 kWh Turbine: 112.9 kWh</td>
<td>77262.5 Yuan</td>
<td>Capital cost would be paid back in 9 years (maintenance cost and tax for generation income are included, but not PV supporting frame and installation labour) Capital cost would be paid back in 15 years (all included)</td>
</tr>
<tr>
<td>B orientation 15° degrees towards the southeast, 20° tilted</td>
<td>4.86kWp PV+1.5kW Turbine</td>
<td>PV: 5490.8 kWh Turbine: 112.9 kWh</td>
<td>89115 Yuan</td>
<td>Capital cost would be paid back in 10 years (maintenance cost and tax for generation income are included, but not PV supporting frame and installation labour) Capital cost would be paid back in 18 years (all included)</td>
</tr>
</tbody>
</table>

* Data provided by the system supplier – Guangzhou HY Energy Technology Limited Corp.

One issue identified when matching the demand side load to generation capacity is that the kitchen should not be heated or cooled by the ASHP system, because 1) the ambient temperature in winter is comfortable enough without providing extra heating; 2) the maximal available floor and ceiling area can not provide enough cooling capacity in summer to ensure the comfort level during the short cooking period; and 3) such ‘not useful’ episodic load pushes the ASHP system’s electricity consumption far beyond the average monthly onsite generation capacity in the cooling season, therefore, significantly lower down the autonomous energy ratio. As a result, detachable air conditioner is proposed to solve the comfort problem of the kitchen, as it can be run in a short time and the main ASHP can be shut off during that period.

**Balancing storage**

It has been discussed above that in the studied project, insulation can only be set to a level which satisfies the local design codes and regulations, but not the maximum achievable potential of the proposed strategy. This is largely due to the cap of budget set up by the developer for their commercial benefits. The design of local renewable generation system highlights that occupants' benefits from feed-in-tariff corresponds to the autonomous energy
rate rather than export-to-grid ratio, therefore, the storage strategy will play a key role in providing the comfort at needed time, whilst maximising local renewable electricity usage, by shifting ASHP system’s operation time closer to the onsite peak generation period.

A demand side load simulation with the proposed envelopes showed that it would take 2 hours to heat up the building and 2 days to get the whole house to a stable thermal status in winter. This corresponds to 3 hours to cool and 3 days to be stably cool in summer, due to the system’s smaller capacity for cooling, which is restrained by condensation issue. Therefore, on top of the optimised energy saving operation schedule, cost saving schedules could be further investigated based on the 2 or 3 hours’ ‘shifting load’ capacity of the envelope (Table 4). Such load shifting mode aims to deal with the fabric load at the peak generation time, and store the heat/coolth for the evening use. Thus, there would be more local electricity use, which means better feed in tariff gains. However, it also operates slightly longer, which means more energy consumption, so detailed simulation as well as commissioning is needed to find the balance point.

Table 4. Two operation schedules based on different priorities

<table>
<thead>
<tr>
<th>Aim</th>
<th>Season</th>
<th>Operation schedule – primary test</th>
<th>Week day</th>
<th>Hot water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy saving</td>
<td>Winter</td>
<td>19:00 – 01:00 (6 hours)</td>
<td>12:00 – 14:00 + 19:00 – 00:00 (7 hours)</td>
<td>Cannot be simulated out because of the heat recovery design of the ASHP system</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>16:00 – 24:00 (8 hours)</td>
<td>12:00 – 15:00 + 20:00 – 01:00 (8 hours)</td>
<td></td>
</tr>
<tr>
<td>Cost saving</td>
<td>Winter</td>
<td>12:00 – 14:00 + 19:00 – 00:00 (7 hours)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>12:00 – 15:00 + 20:00 – 01:00 (8 hours)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5 Integration results and discussions

The design framework highlighted the conflicts between limited radiant surface areas and needed heating/cooling capacity at very early stage, so the architects and HVAC engineers can together work out the innovative design strategy, which uses four concrete slabs with embedded water loops as extra layer on top of them, rather than traditionally three layers of slab for ground or ceiling. Such strategy fits the townhouse building form, can provide the needed comfort at the occupied time by the available radiant surfaces, increases the active thermal storage capacity, and does not reduce the occupants’ usable areas.

With the guidance of the optimised design framework, the following predicted energy performance has been achieved (Table 5).

Table 5. Predicted annual heating and cooling electricity demand v.s. local generation

<table>
<thead>
<tr>
<th>Aim</th>
<th>Heating (kWh)</th>
<th>Cooling (kWh)</th>
<th>Local generation in heating season (kWh)</th>
<th>Local generation in cooling season (kWh)</th>
<th>Local generation in other seasons (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy saving mode</td>
<td>2198.6</td>
<td>896.3</td>
<td>1820.9 Jan, Feb, Mar, Nov, Dec</td>
<td>1776.2 Jun, Jul, Aug</td>
<td>2006.5 Apr, May, Sep, Oct</td>
</tr>
<tr>
<td>Cost saving mode</td>
<td>2378.3</td>
<td>912.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: For the calculation of heating and cooling electricity demand, the average COP of the ASHP system is 3 for heating season and 3.5 for cooling season, according to the user manual of the ASHP provided by TREND (the supplier of this project).

However, there are some fundamental limitations of the predicted performance, which are related to the simulation tools rather than the optimised design framework. The first one is the energy consumption of hot water. The ASHP air-to-water multiple supply system chosen in this case study recovers some wasted heat from the evaporator first, and then increases
the water temperature using an electric heater in the hot water tank. Such process cannot be
simulated by any existing tool available. The second limitation is the thermal storage capacity.
HTB2 treats the envelopes as different layers of materials, so the embedded water loops layer,
which is mixed with loops, inside water, and surrounding pea gravel concrete, cannot be
reflected in the thermal mass calculations. For this case, the whole water loops layer was
calculated as pea gravel concrete, which in fact underestimates the whole floor’s thermal
storage capacity. Such limitation would very likely occur in other simulation tools too. But the
optimised design framework can identify these ‘predictable gaps’ in very early design stage,
therefore, enabling some empirical design to help improve performance.

6 Conclusions

The optimised design framework divides the whole design process into modular elements of
a building, and then groups certain modules together with a shared feature in the design
process. It can highlight the most overlapped and interactive elements in conceptual design
stage, therefore, help the design team to make the most holistic decisions at conceptual
design stage.

Such optimised design framework can help the stakeholders understand and identify
the issues which fundamentally influence their own work but which they are not necessarily
familiar with or aware of at the early design stage (such as the ‘kitchen load changes HVAC
system design’ example explained in this paper).

Such optimised design framework can get simulation assisted design more focused on
different stages and create more sharable information for the whole design team, therefore,
the speed of the whole design process can be accelerated, and consistency can be better
assured across stakeholders in different disciplines (such as the needed radiant surface area
from ceiling and floors, and how they are innovatively designed in the studied case).

The earlier adoption of such optimised design framework, the more cost savings can be
obtained with less effort. For the studied case, if the benefits of pitched roof can be
recognised in the planning stage, the PV-turbine hybrid system would have a better chance
to be integrated with the building for much less cost. Because to compromise with the flat
roof which embeds water loops above the slabs, suspending steel frames with fixation points
at the parapet wall is the only choice to support the PV panels, and this causes 35% increase
of capital cost for the generation system compared with the normal PV-turbine hybrid system.
Such frame cost will be much less in a pitched roof integration strategy. Moreover, when PV
is integrated with pitched roof, there would be extra roof area for solar thermals, and then
the autonomous energy rate could be further increased because low temperature radiant
heating and hot water would have more renewable energy source.

However, the optimised design framework cannot solve all the integration problems,
because some design strategies need very detailed calculations from different disciplines to
finalise the optimal choice. For example, the optimal operation schedule, which consider both
the biggest energy saving potential and the occupants’ best financial benefits (based on the
local feed-in-tariff policy), will need the hourly profiles of local renewable generations,
demand side loads of heating, cooling and hot water, and the envelope’s load shifting capacity.
Such integration cannot be solely solved by simulation assisted design, because of the
knowledge and information gaps in both theory and practice. In such case, commissioning the
whole system with detailed monitoring of the energy flow would play the key role to
understand the profiles, and give designers needed information to formulate the optimal
schedule for the holistic system in the operation stage.
References


Acknowledgments

The design framework has been developed within the scope of a PhD work at Cardiff University. The case study has been sponsored by XI'AN XIAOYUAN TECHNOLOGIES CO., LTD.
The choice and architectural requirements of battery storage technologies in residential buildings

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Abstract: This study has been undertaken to gain a better understanding regarding the choice and architectural implications of battery storage technologies in a future built environment benefiting from renewable energy systems and energy storage technologies. As no models or tools have been found dealing specifically with the size of energy storage systems, this work has partially addressed this shortcoming through the consideration of a framework, within which these issues are explored. The study assessed the requirements of nine battery technologies for different residential building scales at the distribution level in the UK using quantitative methods. Three scenarios for 2030 were considered; the business as usual scenario, a scenario assuming electrification of heating and energy efficiency measures and a scenario in which one electric vehicle is assumed for each house. After deriving the nominal capacity for each technology and identifying key aspects for building integration, several spatial and other requirements, including footprint, volume, mass and cost for the scales of interest were estimated in each scenario considering daily autonomy. The investigation led to a schematic characterisation of the battery technologies according to their suitability across these requirements and their applicability in different building scales. The study showed that the architectural implications of the battery technologies’ integration considering daily autonomy are of little importance to designers. Attention should be given when more than one day of autonomy is applied. The choice of the most suitable technology according to its applicability in different building scales and different daily autonomy periods should also be carefully assessed.

Keywords: battery technologies, energy storage, residential buildings, scenario modelling, architectural implications

Introduction

In the last two decades, sustainability and the irreversible depletion of natural resources has been the subject of constant debate in a global scale. The energy sector today is mainly responsible for the greenhouse gas emissions. Emissions coming from energy-related activities accounted for 68% of the global emissions in 2005 (International Energy Agency 2012) and the building sector is found to be in charge of over 40% of the total energy consumption in Europe (World Business Council for Sustainable Development 2010). Identifying opportunities to reduce this consumption has become a priority in the global effort to deal with climate change. In addition, a very ambitious target set by the EU entails a significant CO₂ reduction by 80 to 95% by 2050 compared to 1990 levels (European Council 2014). An increasing demand in the electricity sector is anticipated in the upcoming years due to the extension of the electrification of different regions worldwide, the increase in energy consumption due to economic growth, the use of electrical energy for heating and cooling and the use of electricity in the transport sector (DECC 2011). Electricity is therefore likely to become a universal and versatile source of low carbon energy for the building sector, but at the same time this is debatable due to scenarios that favour an energy mix in the domestic energy consumption (The Institution of Mechanical Engineers 2014). Expansion of the electricity generation from renewable energy sources is already at the forefront of energy planning and along with electrical energy storage, they are expected to play a key role in the future built environment (Teske et al. 2010; European Commission 2010), contributing to carbon emissions reductions.
The aim of this study is to investigate the architectural requirements of battery storage technologies in residential buildings, which account for the biggest share among commercial, industrial, agriculture, public administration and transport sectors (U.S. Energy Information Administration 2014). The investigation addressed battery integration at building or community scale in the UK, considering only high energy battery storage applications in grid-connected systems, providing the possibility of ‘island’ mode operation for several days. The research work indicates what considerations architects would need to give to this subject in the design of buildings in the future, where electrical energy storage systems are likely to be part of the design, as indicated in numerous studies (Droege 2008; Inage 2011). As no models or tools have been found dealing specifically with the size and location of energy storage systems (Tan et al. 2013), this research work has partially addressed this shortcoming through the consideration of a framework, within which these issues are explored. The presented work could facilitate making informed design decisions with regard to energy storage systems in the medium term from the end-users’ point of view.

Methodology

In this study nine battery technologies were investigated, the data for which were derived from (Chatzivasileiadi et al. 2013). The technologies are applicable to new or existing buildings. After establishing a baseline scenario in 2015 (BS 2015), three scenarios in 2030 were explored: the business as usual scenario (BAU 2030), a scenario assuming electrification of heating and energy efficiency measures (EE 2030) and a scenario in which one electric vehicle is assumed for each house as well (Te 2030). The investigation is based on the electricity consumption data for UK households in the above scenarios derived from a previous study (Chatzivasileiadi et al. 2017). The data, which inform the effective capacity of the battery, are derived in ranges, meaning that the lowest and highest consumption values correspond to low and high consumption households respectively. The study focuses on the final level of distribution in the UK and the number of electrically heated households supplied at this level was found to be 75 (UK Power Networks 2013), which set the upper boundary of the community scale in this study. Intermediate scales were also created for additional reliability on the results.

In order to specify the electricity storage requirements for the residential sector, three steps were followed. First, the specification of the nominal capacity of the battery bank was calculated, then the technologies’ applicability in the different scales was assessed and finally the specification of the technologies’ spatial and cost requirements were estimated based on the nominal capacity values. As the requirements for nominal electricity storage capacity are higher in winter than summer and the battery is assumed to be used all year round, the sizing of the storage system was based on winter’s values. For the values that appear in ranges, two separate sets of data and graphs were produced. Thus a low range and a high range were derived respectively, as indicated in the figures.

Electrical energy storage capacity for the nine battery technologies and their applicability at the different scales

For the calculation of the nominal battery capacity, the following dimensionless parameters were identified as critical to the sizing of the storage system and were therefore considered: round-trip efficiency ($\eta_{b}$), daily self-discharge factor ($k_{sd}$), depth of discharge (DOD),
autonomy period\(^1\), temperature factor (\(k_t\)), aging factor (\(k_a\)), design margin (DM) and the inverter’s efficiency (\(\eta_{\text{inv}}\)). A schematic diagram of electricity flow through a storage system including the above parameters is presented in Figure 1 and the associated values for these parameters are included in Table 1.

![Figure 1: Illustration of electricity flow through a storage system (author’s own)](image)

Table 1. Parameters considered and associated values [information compiled from (Chatzivasileiadis et al. 2013; IEEE 2011; Trojan Battery Company 2013; Alcad 2012; Riffonneau et al. 2011)]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Round-trip eff. (\eta_{\text{batt}})</th>
<th>Lifetime (cycles)</th>
<th>DOD %</th>
<th>Self-discharge/day (k_d)</th>
<th>Temperature factor (k_t)</th>
<th>Aging factor (k_a)</th>
<th>Design margin DM</th>
<th>Invert. eff. (\eta_{\text{inv}})</th>
<th>Spatial requirement (m^2/kWh)</th>
<th>Energy density kWh/m(^3)</th>
<th>Specific energy Wh/kg</th>
<th>Investment energy cost €/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb-acid</td>
<td>0.8</td>
<td>1200</td>
<td>50</td>
<td>1.003</td>
<td>1.11</td>
<td>1.25</td>
<td>1.1</td>
<td>0.9</td>
<td>0.057-0.22</td>
<td>40-80</td>
<td>27-50</td>
<td>50-300</td>
</tr>
<tr>
<td>NiCd</td>
<td>0.7</td>
<td>1500</td>
<td>75</td>
<td>1.006</td>
<td>1</td>
<td>1.25</td>
<td>1.1</td>
<td>0.9</td>
<td>0.009-0.038</td>
<td>&lt;200</td>
<td>45-80</td>
<td>200-1,000</td>
</tr>
<tr>
<td>NiMH</td>
<td>0.7</td>
<td>500</td>
<td>80</td>
<td>1.012</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.032</td>
<td>&lt;350</td>
<td>60-120</td>
<td>240-1,200</td>
</tr>
<tr>
<td>Li-ion</td>
<td>0.9</td>
<td>4000</td>
<td>80</td>
<td>1.003</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.005-0.013</td>
<td>103-630</td>
<td>100-250</td>
<td>200-1,800</td>
</tr>
<tr>
<td>NaS</td>
<td>0.85</td>
<td>4500</td>
<td>80</td>
<td>1.2</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.004</td>
<td>&lt;400</td>
<td>150-240</td>
<td>200-900</td>
</tr>
<tr>
<td>NaNiCl</td>
<td>0.9</td>
<td>2500</td>
<td>80</td>
<td>1.15</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.017-0.022</td>
<td>150-200</td>
<td>125</td>
<td>70-150</td>
</tr>
<tr>
<td>V-Redox</td>
<td>0.75</td>
<td>13000</td>
<td>100</td>
<td>1.1</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.024-0.042</td>
<td>20-35</td>
<td>75</td>
<td>100-1,000</td>
</tr>
<tr>
<td>ZnBr</td>
<td>0.7</td>
<td>2000</td>
<td>100</td>
<td>1.01</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.014-0.025</td>
<td>20-35</td>
<td>60-80</td>
<td>100-700</td>
</tr>
<tr>
<td>Zn-air</td>
<td>0.75</td>
<td>10000</td>
<td>100</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.006</td>
<td>800</td>
<td>400</td>
<td>126</td>
</tr>
</tbody>
</table>

Based on equations (1) and (2) below for the case of one-day and for four-day battery supply respectively, the required nominal battery capacity for each of the nine technologies and for the scales of interest in the different scenarios was estimated.

\[
C_{\text{nom}1} = \frac{C_{\text{eff}}k_tk_aDMk_{\text{sd}}}{\eta_{\text{batt}}DOD\eta_{\text{inv}}} \\
C_{\text{nom}4} = \frac{4(C_{\text{eff}}+C_{\text{eff}}k_tk_aDMk_{\text{sd}})}{\eta_{\text{batt}}DOD\eta_{\text{inv}}} \tag{2}
\]

\(^1\) The investigation on both 4 and 1 days of autonomy, which was based on current rules of thumb (Murphy 2011) and current practices (Little 2013), is useful for 2 reasons: first, the nominal capacity is not linear, so the capacity for 4 days will not be 4 times the capacity required for 1 day. This is due to the inconsistent electricity consumption values on weekdays and weekends. Secondly, depending on the nominal capacity required, some technologies are likely to be unavailable according to their energy rating, which would be useful to explore.
where $C_{\text{nom}1}$ is the nominal capacity of the battery for one day
$C_{\text{eff}}$ is the effective capacity of the battery for a day in the weekend
$C_{\text{nom}4}$ is the nominal capacity of the battery for four days
$C_{\text{eff}}$ is the effective capacity of the battery for a day in the weekend
$C_{\text{eff}}$ is the effective capacity of the battery for a weekday

For the assessment of the batteries’ applicability in different scales, the nominal capacity values were compared against the energy rating range for each battery technology found in (Chatzivasileiadi et al. 2013). Where the required nominal capacity value was outside the energy rating range, the technology was considered unsuitable for the respective scale².

Footprint, volume, mass, investment cost and levelised cost of electricity

The footprint, volume, mass, the investment cost and the levelised cost of electricity (LCOE) for the nine battery technologies at different scales were derived, based on the nominal battery capacity values calculated in the previous section and the information included in Table 1. The analysis was performed using the columns referring to the spatial requirement (m²/kWh), the energy density (kWh/m³), the specific energy (Wh/kg), the investment energy cost (€/kWh), the round-trip efficiency ($\eta_{\text{batt}}$), the lifetime in cycles and the DOD from Table 1. The LCOE of the battery, $C_{\text{LCOE}}$ (€/kWh of electricity generated over lifetime of technology), is calculated using equation (3) below. Equation (3) is a synthesis from the equations presented in (Dennis Barley & Byron Winn 1996) and (Dufo-López et al. 2007).

$$C_{\text{LCOE}} = \frac{C_{\text{batt}}}{C_{\text{nom}} \cdot \eta_{\text{batt}} \cdot N_{\text{cycles}} \cdot \text{DOD}}$$  (3)

where $C_{\text{batt}}$ (€/kWh) is the battery investment cost
$C_{\text{nom}}$ is the nominal capacity of the battery
$\eta_{\text{batt}}$ is the round-trip efficiency of the battery
$N_{\text{cycles}}$ is the battery’s cycle life at the specified DOD and
DOD is the depth of discharge

For the values that appear in ranges, two separate sets of data and graphs are produced and presented in this section. Thus through the consideration of the minimum and maximum values a low range and a high range are derived respectively, as indicated in the figures.

Results

As there is a linear correlation between the number of properties and the derived values regarding nominal battery capacity and spatial requirements, the results for up to 5 properties are displayed. Due to the limited suggested length of this paper, it was impossible to include the illustrations for all explorations, so a selection is presented; however, the discussion covers the full scope of this study.

² It should be noted that if the required nominal storage capacity is lower than a technology’s lower bound of the energy rating range, this does not mean that the technology is not applicable; yet the battery would possibly be oversized. This would only be an energy efficiency issue, but not an applicability issue.
Electrical energy storage capacity for the nine battery technologies and their applicability at the different scales

An illustration of the battery technologies’ nominal capacity values and their applicability or not to community scales up to 5 households for 4 days of autonomy is presented in Figure 4. In case of no applicability, the coloured blocks - which the columns consist of and which address minimum or maximum nominal capacity values - are void. Minimum and maximum nominal capacity correspond to low and high consumption households respectively. So, for example, looking at Figure 4, as NaS is not applicable for one or two low consumption households in BS 2015 and BAU 2030, the yellow and blue blocks in the NaS minimum column in the graphs for BS 2015 and BAU 2030 are void.

Figure 2: Nominal capacity and applicability of battery technologies for different scales up to 5 households if 4 days of autonomy are applied in winter in all scenarios

It was observed from this exploration that the Pb-acid and Li-ion technologies already have a wide enough energy rating range to be able to serve all scales at distribution level for an autonomy period of 4 days in all scenarios in 2030. NaNiCl would be capable of serving a community of up to about 25 residential buildings, as is the case for ZnBr. These technologies would not be able to be applied to a larger district scheme, due to the limitations posed by the technologies’ energy rating range. Moreover, V-Redox would be able to serve up to 25 houses regardless of their electricity consumption and up to 75 houses if their consumption was towards the lower bound of the range assumed in this study. This is the case for Zn-air too. As shown in Figure 4, NiCd and NiMH technologies with their current limited energy ratings cannot meet the requirements for a group of households bigger than 5. In addition, as seen in Figure 4, NaS is able to serve all scales in all scenarios, except a single household in EE 2030 or a single household or two with generally low consumption in the rest of the scenarios. This can be explained by the fact that NaS cells are primarily suitable for large-scale, non-mobile applications such as grid energy storage (Doughty et al. 2010). This is attributed to the batteries’ high operating temperature range of 300°C to 350°C and the highly corrosive nature of the sodium polysulfide discharge products.
Footprint, volume, mass, investment cost and levelised cost of energy

The Te 2030 scenario in the case of four days of autonomy has been chosen as an example for illustration in this section. The respective graphs for footprint, volume, mass, investment cost and LCOE for communities comprising up to 5 households in Te 2030 are presented in Figure 3 below. On the left hand side of the figure the low range of the various aspects is presented, while the high range is on the right hand side.

Figure 3. Comparison among footprint, volume, mass, investment cost and LCOE of battery technologies for four days of autonomy in Te 2030
Discussion

The Te 2030 scenario for the case of four days of autonomy has been chosen as an example for discussion, as the comparisons across scenarios are similar due to the linearity of the values. Figure 3 allows for comparisons among the quantitative aspects of integration assessed in this chapter. The technologies are compared vertically across the aforementioned aspects and the strengths and the weaknesses of each battery option are then discussed. From the investigation regarding four and one days of autonomy it was observed that the different aspects present a similar picture. The only aspect that is different and could affect the ranking of the technologies is their applicability to the different scales.

Pb-acid requires the biggest nominal capacity and is by far the most unfavourable technology in terms of footprint, volume and mass. However, is applicable at all scales for both one and four days of autonomy, which is a convenient aspect. It has medium investment cost and relatively low LCOE, which makes it an economic option.

NiCd is just behind Pb-acid as regards the nominal capacity and the mass and is only able to serve up to about 5 houses in the case of four autonomy days depending on the scenario, rendering it largely unfavourable in terms of these three aspects. If one autonomy day is required, NiCd would then be problematic for communities of 25 or more households. It has a big footprint especially when the maximum spatial requirement is assumed and medium volume. It has the highest investment cost per connection and high LCOE, making it an expensive storage option.

NiMH has medium capacity requirement and has little applicability, being able to serve up to 4 houses in the case of four autonomy days depending on the scenario. If one autonomy day is required, NiMH would then be problematic for communities of 10 or more households. It also has a quite big footprint especially in the case where the minimum spatial requirement has been considered. It has medium volume and mass values. It has high investment cost and the highest LCOE, making it the most expensive option over its lifetime.

Li-ion ranks second in terms of nominal capacity requirement and being applicable at all scales for either one of four days of autonomy makes it a highly favourable technology. It is among the top three technologies regarding the footprint and ranks second in terms of volume and mass when the maximum energy density and specific energy values are assumed. Li-ion, along with NaS, are among the most expensive technologies in terms of investment cost in both the low and high range graphs, yet it has medium to low LCOE assuming a great reduction in investment cost by 2030 due to R&D.

NaS has medium nominal capacity requirement and might not be applicable for communities up to 3 households if four days of autonomy are required depending on the scenario. In the case of one autonomy day, NaS might be problematic for communities of 10 or less households. It ranks either first or second as regards the footprint. NaS is among the top three technologies as regards the volume and the mass, regardless of whether the minimum or maximum energy density and specific energy values is considered. It has high investment cost, but medium to low LCOE.

NaNiCl has medium nominal capacity requirement and is not applicable in communities consisting of 25 houses or more if four days of autonomy are required. Yet in the case of one autonomy day NaNiCl is applicable in all scales. It is a medium option regarding footprint. It ranks third in terms of mass if the maximum specific energy values are assumed and fourth if the minimum specific energy values are assumed. It has medium volume range like NiCd and NiMH. It has very low investment cost and LCOE.
V-Redox has medium to low capacity requirement and might be problematic in serving communities of 50 households or more in the case of four autonomy days. Though it is applicable in all scales if one autonomy day is required. It is a relatively unfavourable technology regarding its footprint. It has medium mass values and considerably unfavourable volume requirements due to its low energy density. It has medium to low investment cost and the lowest LCOE assuming the low investment cost value expected in 2030.

ZnBr has medium to low capacity requirement and is likely not to be applicable to communities comprising 25 households or more in the case of four autonomy days. If one autonomy day is required, ZnBr might be problematic in serving a group of 3 or less households. It is a medium option regarding footprint, ranking fourth if the minimum value for spatial requirement is assumed. It has medium mass values and just like V-Redox, it is unfavourable in terms of volume. It has low or medium investment cost in the low and high cost range graphs respectively and medium to low LCOE.

Zn-air requires the least nominal capacity and in terms of applicability in the case of 4 autonomy days it performs exactly the same as V-Redox, being potentially problematic for communities of 50 households or more. If one autonomy day is required, Zn-air might not be able to serve communities comprising up to five households. It is one of the top three technologies regarding footprint and also the top technology in terms of the lowest volume and mass, exhibiting the highest energy density and specific energy among all battery technologies. It also has medium to low investment cost and one of the lowest LCOE values.

Regarding community-wide applications, e.g. 75 households, and considering the minimum footprint values from Table 1, the required space for the suitable battery technologies in Te 2030 under four days of autonomy ranges from 1,850-3,300m$^2$ for Pb-acid, 65-116m$^2$ for Li-ion and 66-118m$^2$ for NaS. Assuming the minimum volume values from Table 1, the required volume ranges from 810-1,450m$^3$ for Pb-acid, 126-225m$^3$ for Li-ion and 41-74m$^3$ for NaS. Alongside the above spatial requirements, future research could include further architectural considerations, for example chemical gases release in the room and fire safety considerations, ventilation requirements for the room as well as the identification of the structural implications arising from the mass of the batteries.

**Volumetric analogy**

In order to assess the implications of the batteries’ volume on building design, a volumetric analogy was performed considering a standard washer device measuring 0.8m*0.8m*0.9m$^3$ (BUILD 2018) and assuming one household$^4$. A volumetric analogy is presented for 4 and 1 days of autonomy in Figure 4.

---

$^3$ The dimensions refer to (width*depth*height) respectively.

$^4$ The investigation in this section addresses only the scale of a single household, as the number of washers is proportional to the number of households. The impact will therefore be proportional to the number of households.
As shown in Figure 4, considering the maximum energy density values that are more likely in 2030 due to R&D, a single household would need a maximum equivalent volume of about 15 standard washers (Pb-acid, V-Redox and ZnBr technologies) for 4 days of autonomy. The rest of the technologies could be used as an alternative in cases of limited space, as they would require an equivalent amount of less than 5 standard washers. In the case of 1 autonomy day, assuming the maximum energy density values, a single household would need a maximum equivalent volume of about 2 standard washers. This volume would apply again for Pb-acid, V-Redox and ZnBr technologies. The rest of the technologies would require an equivalent amount of less than 1 standard washer. The volumetric analogy shows that the implications of the integration of battery technologies on the spatial requirements are of little importance to designers. Greater attention should be given in the case of four days of autonomy, which indicates that consideration should be generally given for any period of over four days. For intermediate periods further analysis is suggested.

**Gravimetric analogy**

In order to further assess the implications of the batteries’ volume on building design, a gravimetric analogy was performed considering the same standard washer device, assuming...
a washer with a mass of 80kg (BUILD 2018). A gravimetric analogy is presented for 4 and 1 days of autonomy in Figure 5.

As shown in Figure 5, considering the maximum specific energy values that are more likely in 2030 due to R&D, a single household would have a maximum equivalent mass of about 200 standard washers for 4 days of autonomy. This mass is remarkably high, but it would apply only for Pb-acid, which have low specific energy values. In order to circumvent any structural limitations in the design of the floor, Li-ion, NaS and Zn-air could serve as good alternatives, having only 5-10% of this mass, thus an equivalent mass of 5-20 washers. In the case of 1 autonomy day, assuming the maximum specific energy values, a single household would have a maximum equivalent mass of about 25 standard washers. This mass would apply again only for Pb-acid, whilst Li-ion, NaS and Zn-air would have an equivalent mass of less than 3 standard washer. The gravimetric analogy shows that the implications of the integration of battery technologies regarding their mass and associated structural requirements of the floor are of little importance to designers. Greater attention should be given when more than one day of autonomy is applied.

Based on the findings from this study, Table 2 below presents a schematic characterisation of the battery technologies according to their suitability across the

![Gravimetric analogy](image)
integration criteria as well as their applicability in different building scales. The picture presented there is that of the low range scenarios and is based on the minimum spatial requirement, maximum energy density, maximum specific energy and minimum investment cost from the range in Table 1, as these figures are more likely in 2030 due to R&D.

Table 2. Illustration of suitability criteria for battery technologies in the low range scenarios in 2030

<table>
<thead>
<tr>
<th>Nominal capacity</th>
<th>Applicability in scales</th>
<th>Footprint</th>
<th>Volume</th>
<th>Mass</th>
<th>Investment cost</th>
<th>LCOE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 day</td>
<td>4 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb-acid</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>NiCd</td>
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<tr>
<td>NiMh</td>
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<td></td>
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<tr>
<td>Li-ion</td>
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<td></td>
<td></td>
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<tr>
<td>NaNiCl</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>V-Redox</td>
<td></td>
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<td></td>
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<tr>
<td>ZnBr</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Zn-air</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

The architectural implications of the integration of battery storage technologies considering daily storage are of little importance to designers. Attention should be given when more than one day of autonomy is applied. The choice of the most suitable technology according to its applicability in different building scales according to different daily autonomy periods should be carefully assessed. More specifically, in the case of an autonomy period of 4 days, as the number of properties increases, fewer technologies are available. In the case of an autonomy period of 1 day, for 10 households all technologies are available and then on both sides of it, i.e. for either more or less households, the number of technologies gradually decreases. Hence, only 6 technologies are available for one household and only 7 for 75 households. In
addition, Pb-acid and Li-ion technologies already have a wide enough energy rating range to be able to serve all scales at distribution level for an autonomy period of 4 days in all scenarios in 2030. NaNiCl and V-Redox are also suitable at all scales if 1 day of autonomy is applied.

In terms of the suitability criteria, if a technology is the most favourable in terms of nominal capacity, footprint, volume or mass doesn’t mean that it is the most favourable one in terms of investment cost too and vice versa. Li-ion, NaS and Zn-air are the top three technologies exhibiting the smallest footprint and Pb-acid the last one having the biggest footprint. Regarding volume, in the case that the maximum values are considered (which are more likely in 2030 due to R&D), the top three are Zn-air, Li-ion and NaS. Regarding mass, in the case where the maximum values are considered, the top three are Zn-air, Li-ion and NaS.

In terms of investment cost, in the case where the minimum cost per kWh is considered, NaNiCl, ZnBr and V-Redox are the top three technologies having the lowest investment cost. In terms of LCOE Zn-air, NaNiCl and V-Redox are the top three options, while NiMH, NiCd and Pb-acid rank last.

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UK Power Networks, 2013. E-mail communication with UKPN expert.
Numerical Investigation of Geometrical Design for Transpired Solar Collector Performance

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Abstract: In the UK, a large amount of energy has been used for heating and cooling the buildings. Without designing an efficient envelope, it is not possible to improve the performance of buildings and achieve a reduction in building energy consumption and greenhouse gas emissions. One method of reducing building energy dependency and limiting greenhouse gas emissions is through introducing newly solar thermal technologies like transpired solar collectors (TSCs) into the building envelope. It contains a perforated metal sheet attached at a certain distance to the building wall to create a plenum and the metal profile is heated by solar radiation, which then transfers the heat to the plenum air. While, the air is cross the perforation hole and then sucked to the building inside by a fan as part of ventilation services. TSCs is one of the most efficient solar thermal conversion technologies and parametric study indicated that geometrical design like the geometry of perforated-hole has a huge influence on TSCs performance. Literature reviews and industrial reports displayed that there are different types of holes available for TSCs design such as the round hole, square hole, and another special hole like star/cross. However, there is no or limited study on the impact of the different shape of a hole on TSCs performance. This paper presents a numerical investigation with using ANSYS Fluent software on TSC performance due to the absorber plate profile with two different types of holes (round hole and square hole). The results indicate that (i) the profile with round hole provide 14% higher outlet temperature compared to the profile with a square hole and (ii) the collector with higher heat transfer coefficient absorber plate would give higher outlet temperature.

Keywords: Solar energy; Transpired Solar Collector; Energy Performance; Hole Shape; Numerical modelling

Introduction

In Europe, roughly 40% of total energy usage on Buildings operations, which covers 39% of total energy usage, with approximately half of building energy consumption due to the demand on heating and cooling the buildings in the UK (Hall et al. 2011, Pérez-Lombard et al. 2008). Designing an efficient envelope of the building is a crucial domain to generate higher building performance via achieving a reduction in building energy usage and greenhouse gas emissions (Shukla et al. 2012). However, introducing newly solar thermal systems like transpired solar collector (TSC) into building envelope has been seen as one of the most efficient technology to reduce building energy dependency and limiting CO₂ emissions from the buildings (Wang, Y. et al. 2017).

TSC is one of the most efficient solar thermal technology and it has been popular to use during engineering processes like dry agricultural products, long-term warehouse and preheating ventilation air for buildings (Brown et al. 2014). Also, it has been attracting a huge number of scholars to do research in order to increase TSC technology. The parametric study indicated that
geometrical design like the geometry of perforated-hole and pitch size has a huge influence on TSCs performance. Literature review and industrial reports advised that there are various types of holes available for TSC design such as round hole, square hole, and other special holes like star/cross (Anon. n.d.). It can be assumed that the performance of sheets varies due to the different geometry of hole and pitch size (Croitoru et al. 2016). For instance, it is conducted that the heat transfer to the air and the outlet air temperature reduces due to the increase in hole diameter (Rad and Ameri 2016).

Therefore, the overall goal of this research work is to investigate the impact of geometrical design like hole perforation and pitch size on TSC performance. However, the present work is to study numerically via using ANSYS Fluent software the impact of two different hole geometry like round and square hole with the same dimension (1 mm) on TSC performance. This paper will propose a geometrical design of TSC and its impact on TSC performance. It also investigates the impact of the profile property (for instance, heat transfer coefficient) on TSC performance (mainly on air temperature rise).

**Overview on Transpired solar collector**

TSCs are used as building cladding system (known as building integrated transpired solar collector system) to generate heat by gaining solar irradiation. It contains a wall mounted perforated metal sheet as an absorber plate, which is attached at a certain distance to the building wall in order to create air cavity known as the plenum (Figure 1). In this system, the metal profile is heated by solar radiation, which then transfers the heat to the plenum air and in the meantime, the air is cross the perforation hole and is then sucked to the building inside by using the lower velocity of a fan as part of ventilation services. More importantly, in this whole process, the geometrical design of TSCs seems curial to the performance of transpired solar collector.

![Figure 1. (a) Schematic of building integrated transpired solar collector system (Shukla et al. 2012); (b) Transpired solar collector at Willmott Dixon Community Healthcare Campus, UK (Brown et al. 2014)](image)

In terms of application in the UK, TSC technology has been popularly integrated into numbers of new and existing buildings, for instance, Fig. 1b displays the application of TSC on south-façade of healthcare building. Another typical example is that Jaguar Land Rover Training
Academy applied TSC technology in 2012 with the operational collector area of 268m² and it was believed that the TSC technology saved over 80000 kWh of energy yearly with generating 20% of total building energy requirements and it could reduce 13 tons of CO₂ emissions per year. However, there are still some potential to improve the implantation of TSC via improving the geometrical design of TSC.

Methodology

In this paper, the work focuses on investigating TSC thermal performance experimentally and numerically. Experimental work was undertaken in a laboratory under control-environmental conditions where the ambient and outlet temperatures and the mass flow rate through the TSC for one specific dimension of hole geometry and pitch size is measured. In terms of numerical modelling, the physical TSC system is recreated in ANSYS Fluent software to capture the multi-scale fluid flow behaviour over the absorber plate, within the perforated holes, and through the air cavity (plenum). For the geometrical design of TSC, the very small size of perforation holes with a diameter of 1 mm over the large absorber plate surface area (1 m × 1 m) of flat absorber plate could bring up a multi-scale geometry. The numerical investigation also reduces the research cost by reducing computational spending and a representative section of a full physical domain. Moreover, the experimental data from the lab is used in ANSYS Fluent software to validate the model as a boundary condition during the simulation process.

![Figure 2. Physical domain of TSC in ANSYS Fluent Design Modeller](image)

The software addresses the steady-state, three-dimensional, conservation equation of mass, momentum, and energy for the physical TSC domain (Figure 2). The Reynolds-Averaged Navier-Stokes (RANS) equation and the Realizable Renormalization Normal Group k-ε (RNG k-ε) are applied for turbulence cases since RNG k-ε turbulence model performs better considering of accuracy and stability for numerical modelling (Li and Karava 2012). A second-order upwind scheme was adopted for all variables except pressure as the discretization of pressure is based on a staggered scheme. Also, the SIMPLE algorithm was employed to connect the pressure and momentum equations. The solution is set to reach converge when the total of the absolute
normalized residuals for all the cells in the flow domain become less than 10^-6 for all variables. In addition, the interaction between the boundary layer and solid surfaces has been sorted. Moreover, all heat transfer model has been used, in particular, solar radiation is modelled via the solar load model that can be set for a specific time, a certain date and sun direction. However, the actual solar radiation intensity data was also available for measurements (Hall et al. 2014). For meshing, the proximity and curvature as advanced size function are used and the inflation is also considered, another section is automatically program controlled. In term of the boundary conditions for this numerical investigation, the input values for certain parameters are decided by referencing accordingly to the recent studies on TSC performance as it is shown in Table 1.

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>(Bokor et al. 2017)</th>
<th>(Leon and Kumar 2007)</th>
<th>(Kutscher et al. 1993)</th>
<th>(Wang, Xiaoliang et al. 2017)</th>
<th>This study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature (°C)</td>
<td>34.25</td>
<td>30</td>
<td>10</td>
<td>11-21</td>
<td>4</td>
</tr>
<tr>
<td>Solar irradiation (W/m^2)</td>
<td>727</td>
<td>700</td>
<td>700</td>
<td>600-950</td>
<td>500</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>3.25</td>
<td>1.20</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Approach velocity (m/s)</td>
<td>NA</td>
<td>0.01-0.03</td>
<td>0.01-0.45</td>
<td>0.011-0.022</td>
<td>0.005-0.03</td>
</tr>
<tr>
<td>Pressure drop across the collector (Pa)</td>
<td>25-80</td>
<td>NA</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Plenum depth (mm)</td>
<td>120</td>
<td>120</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Pitch (mm)</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>20-30</td>
<td>20</td>
</tr>
<tr>
<td>Perforation hole diameter (mm)</td>
<td>1.926</td>
<td>1.25</td>
<td>2</td>
<td>1-2</td>
<td>1</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>0.835</td>
<td>0.31</td>
<td>0.65</td>
<td>0.0013-0.049</td>
<td>0.7</td>
</tr>
<tr>
<td>Absorber material</td>
<td>Steel plate</td>
<td>Mild steel</td>
<td></td>
<td>Corrugated stainless steel sheet</td>
<td></td>
</tr>
<tr>
<td>Solar absorptance</td>
<td>0.95</td>
<td>0.95</td>
<td>0.9</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Thermal Emittance</td>
<td>0.77</td>
<td>0.85</td>
<td>NA</td>
<td>NA</td>
<td>0.85</td>
</tr>
</tbody>
</table>

According to the settings on Table 1, it can be easily found that this investigation on TSC performance is undertaken within no-wind condition as the whole experiment is designed to run in-lab condition where the wind speed is zero. Also, there are some initial values for certain parameters, for instance, the approach velocity is between 0.005 m/s and 0.03 m/s the solar radiation is 500 W/m^2.

Results

A series of numerical modelling has been performed with above initial values settings for main
parameters to investigate the thermal performance of TSC made of the profile with round and square hole via using the k-ε RNG turbulence model and the results from the numerical investigation are shown in details as below in terms of the collector efficiency, air temperature rise for the TSC with round and square holes at the various air mass flow rate (0.005m/s-0.03m/s). Additionally, the impact of the profile property (for instance, heat transfer coefficient) on TSC performance (mainly on air temperature rise) is also demonstrated briefly.

**Effect of air flow rate**

It is generally believed that the mass flux, defined as the mass flow rate, is common to use for controlling the thermal performance of the TSC and the air velocity through the collector is one of the most significant determents influencing the collector efficiency (Badache et al. 2012a). Figure 3 shows the variation of TSC thermal performance with 1mm round hole in terms of air temperature rise due to the different values of air flow rate.

![Figure 3. The impact of approach velocity on air temperature rise](image)

In this numerical modelling, the ambient temperature and solar radiation are set at 4°C and 500W/m² and the air temperature rise (the outlet temperature) would be decreased as the air flow rate increase, which is valid as it is stated by (Badache et al. 2013) that the air temperature rise decline with increasing airflow flux or rate. For instance, the collector will have the highest outlet temperature of 9.8°C when the approach velocity claims the lowest value at 0.005 m/s. Also, the TSC efficiency increases with the growing amount of air flow rate because the heat capacity generally relies on the mass flow rate, which in return induces the higher velocities through the perforations and more heat transfer from the plate to the air inside the air cavity (Badache et al. 2012b). Meanwhile, it is interestingly found that the TSC with the square hole has the same trend as the collector with a round hole.

However, under the same boundary condition settings, the outlet temperature got different temperature distribution due to the collector absorber with round and square hole as it is displayed in Figure 4.
Interestingly, it can be found out that the collector with a round hole obtain higher outlet temperature than the collector with the square hole as it is shown in Fig. 3. For instance, Fig. 3a only has 4 different colours with temperature distribution and Fig. 3b instead has 5 different temperature distribution colour with an additional small size of darker blue colour at the bottom of the circle, which show a lower temperature distribution. In return, the darker blue colour of temperature distribution minimizes the total outlet temperature for the collector with the square hole. Therefore, according to this numerical results, it can be indicated that the absorber profile with round hole provides a 14% higher outlet temperature comparing to the profile with the square hole.

**Effect of heat transfer coefficient of the absorber material**

Multiple numerical modelling has been done on investigating the impact of various absorber plate profile due to its different heat transfer coefficient (25W/m\(^2\) · K, 30W/m\(^2\) · K, 50W/m\(^2\) · K) and the results show that the collector would claim higher outlet temperature with the absorber profile with higher heat transfer efficient (Figure 5).
Fig. 4 shows the impact of various absorber plate due to different heat transfer coefficient on a corrugated thermal solar collector and it is believed that the absorber profile with greater value of heat transfer coefficient would give higher outlet temperature for the collector as more solar energy is easily transferred to the plenum air via the plate with higher heat transfer coefficient (Chabane et al. 2014). In return, it would increase the air temperature rise. For instance, the absorber collector with 50W/m²·K would provide the highest outlet temperature of 9.8°C compared to other sets of absorber plate (Fig. 4). However, the impact of the heat transfer coefficient of the absorber plate has a limited effect on temperature rise as it only increases the outlet temperature by 1 degree Celsius. It can be expected that this result would give a guidance on choosing the materials for the absorber plate profile during the application of TSC. Meanwhile, it can be estimated that the other property of absorber plate including thermal resistance and solar absorptance would have greater impact as these two impact will greatly influence the amount of solar energy collected by the plate. These would be investigated in later work in this research.

Conclusion
The thermal performance of a corrugated transpired solar collector has been investigated numerically with the input from experimental investigation result to analyse the impact of hole shapes (round and square hole with same hole area) and absorber plate property on air temperature rise of the collector. In can be found via this study that:

- The collector efficiency increases with the increasing amount of air flow rate for TSC even with different hole shapes like the round and square hole. However, the collector with round hole claims higher outlet temperature than the collector with the square hole, for instance, the absorber profile with round hole provide 14% higher outlet temperature comparing to the profile with the square hole.
- The property of absorber profile also affects the collector thermal performance, for instance, the collector with higher heat transfer coefficient absorber plate would give higher outlet temperature, in return, which would increase the air temperature rise.
- However, the absorber profile with the property of heat transfer coefficient has limited impact on collector performance, for instance, there is a 1 degree Celsius in outlet temperature due to various heat transfer coefficient property.

Therefore, it can be indicated that the hole shape design and the material selection for the absorber plated generally influence the collector performance and it needs to be considered when applying TSC in the industry in order to increase the performance and efficiency of the solar collector. Also, these numerical modelling results will be validated experimentally in the future as part of the research and it is likely to provide a proper guidance for implementing TSC in the industry.
References


Exploring Potential of Utilizing Smart Materials & Systems in Abu Dhabi, UAE

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Abstract: For centuries, materiality has been merely an element or part of building shelter, however, recently it became a major instrumental and contributor in the design of building’s façade. The new researches and investigations, that are exploiting and experimenting materials, has made architects to start considering the usage of these materials in new, innovative and unexpected ways and in different unconventional conditions and situations. Great deal of the newly advanced and developed materials shows a capability of directly and immediately reacting to different external conditions or to changes in climate, temperature, heat, light, electric field or movement by altering their physical or chemical properties or performing an energy exchange. “Smart Materials” is the term that has been continuously used to define and categorize these materials that have changing properties and can reversely modify their shape, color, elasticity or mechanical characteristics. These materials are of extreme importance for architectural envelopes since they help the building skin to continuously react and adapt to different environmental and climatic changes. This research paper’s goal is to exploit the true meaning of smart materials along with their characteristics and benefits. This paper will include an in-depth understanding of the several types and classifications of smart materials. In addition, this paper will provide an analysis of the weather and climatic conditions of Abu Dhabi, UAE, together with the different suitable climatic design considerations. It will also investigate on the effectiveness, permeability and the applicability of utilizing these smart materials in Abu Dhabi, UAE. As an epilogue and based on the information conducted within this research, summary and conclusion has been made.

Keywords: Smart Materials, Architecture, Sustainability, Climate, UAE

INTRODUCTION

With the development in the field of material science and engineering, there became many new modern, cost efficient and high-quality materials. The 21st century is now witnessing a smart materials era, which is the result of the last evolution in the concept of material sciences. These smart materials respond to the century’s technological needs and bring innovative solutions to persistent long-term problems. They are the new generation that exceeds the conventional and functional materials and structure. (Kamila, 2013)

Smart Materials represent a diverse group of engineered materials. They have the ability to provide a unique and beneficial response when a particular change happens within its surrounding environment. In other words, they are objects that sense and react to external environmental conditions by processing the sensing information and then act upon the external stimuli by significantly altering one or more of their property. These external stimuli may be heat, temperature, light, moisture, pressure, magnetic or electric field, mechanical force and/or even nuclear radiant. Any change that happens to a smart material is reversible meaning that the material can return to their original state once the external stimuli is removed or expires. Smart materials reaction may vary from one material type to another based on their molecular alteration, inherent properties and embedded control systems. (Sadeghi, Masudifar, & Faizi, 2011)
**Characteristics of Smart Materials**

There are five fundamental characteristics that differentiate smart material from any other conventional material used in architecture. Smart materials exhibit the following characteristics:

1. **Immediacy**: smart materials are real-time responders
2. **Transiency**: smart material capable of reacting to more than one environmental condition
3. **Selectivity**: smart materials possess discrete and predictable response
4. **Self-auction**: smart material is of internal intelligence and not external
5. **Directness**: the response is local to the activating stimuli

(Mohamed, 2017) (Addington & Schodek, 2005)

While it is common that the above 5 are smart material’s fundamental characteristics; some authors argue that smart materials can also be grouped into other 3 type’s characteristics according to the above characteristics. This grouping is based on the physical characteristics of smart material. The physical characteristics are usually determined by the mechanism and energy fields by which the input energy, stimuli, to a material is converted. The 3 types group characteristics are:

1. **Property-Changing Capability/Materials – Type I**: These smart materials are materials that endure a change in their property or properties, thermal, chemical, mechanical, optical, magnetic or electrical, as a response to the changing conditions of the material’s environment. The environmental condition can either be ambient or produced by a direct energy input. When a property changing material is exposed to an external stimulus, the internal energy of the material is affected, therefore the material’s inner molecular structure or microstructure will be altered. So, the material absorbs the input energy and undergoes a change. A photochromic material, as an example, changes its ability to reflect color as a response to the change in the amount of light on its surface.

2. **Energy Exchanging Capability/Materials – Type II**: Also known as “First Law Material” after the First Law of Thermodynamics, law of conservation of energy. These smart materials change the input energy into another form in order to produce an output energy. Unlike property changing materials, this kind of material stays the same, yet its energy state undergoes a change; thus, resulting in an exchange of energy from one form to the other. A photovoltaic material, for example, convert light UV radiation energy into an electric current.

3. **Material\Energy Exchanging Capability “Reversible”**: These materials characteristics can be divided into two categories:
   - **Size\Location**: this is based on the fundamental characteristics of smart material which states that smart materials differ than traditional materials in terms of their discrete size and direct actions. A system that contains a component or an element made of smart material will be smaller, require less infrastructural support and will be later deployed in the most effective and functional location.
   - **Reversibility\Directionality**: many smart materials exhibits the characteristics of reversibility or bidirectionality. Smart Materials with reversibility property can return to their original state once the external stimuli pass away. Bidirectionality property of smart materials means that these materials can reverse or switch their input and output energy forms as shown in figure 1. Piezoelectric smart materials, as an example, exhibit this bidirectionality behavior. An applied electric current on piezoelectric materials would cause a mechanical deformation in the material creating
a mechanical force. Or, the opposite, an applied mechanical force on piezoelectric material would cause it to deform and thus generate an electric current. Hence, this material can switch its input and output stimulus accordingly. (Mohamed, 2017) (Addington & Schodek, 2005)

Table 1 below shows the different smart material from each type category and their response to the different input and output stimuli.

Table 1: Type 1 and Type 2 smart materials in relation to input and output stimuli (Addington & Schodek, 2005)

<table>
<thead>
<tr>
<th>TYPE OF SMART MATERIAL</th>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 Property-changing</td>
<td>Thermochromics</td>
<td>Temperature difference</td>
</tr>
<tr>
<td></td>
<td>Photochromics</td>
<td>Radiation (Light)</td>
</tr>
<tr>
<td></td>
<td>Mechanochromics</td>
<td>Deformation</td>
</tr>
<tr>
<td></td>
<td>Chemochromics</td>
<td>Chemical concentration</td>
</tr>
<tr>
<td></td>
<td>Electrochromics</td>
<td>Electric potential difference</td>
</tr>
<tr>
<td></td>
<td>Liquid crystals</td>
<td>Temperature difference</td>
</tr>
<tr>
<td></td>
<td>Suspended particle</td>
<td>Electric potential difference</td>
</tr>
<tr>
<td></td>
<td>Electrothermoleical</td>
<td>Electric potential difference</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE OF SMART MATERIAL</th>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2 Energy-exchanging</td>
<td>Electroluminescents</td>
<td>Electric potential difference</td>
</tr>
<tr>
<td></td>
<td>Photoluminescents</td>
<td>Radiation</td>
</tr>
<tr>
<td></td>
<td>Chemo luminescents</td>
<td>Chemical concentration</td>
</tr>
<tr>
<td></td>
<td>Thermoluminescents</td>
<td>Temperature difference</td>
</tr>
<tr>
<td></td>
<td>Light-emitting diodes</td>
<td>Electric potential difference</td>
</tr>
<tr>
<td></td>
<td>Photovoltaics</td>
<td>Radiation (Light)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE OF SMART MATERIAL</th>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2 Energy-exchanging (reversible)</td>
<td>Piezoelectric</td>
<td>Deformation</td>
</tr>
<tr>
<td></td>
<td>Pyroelectric</td>
<td>Temperature difference</td>
</tr>
<tr>
<td></td>
<td>Thermoelectric</td>
<td>Temperature difference</td>
</tr>
<tr>
<td></td>
<td>Electrostrictive</td>
<td>Electric potential difference</td>
</tr>
<tr>
<td></td>
<td>Magnetostrictive</td>
<td>Magnetic field</td>
</tr>
</tbody>
</table>

**Benefits and Challenges of Smart Materials**

Smart materials and systems provide a wide range of benefits and enormous advantages in the field of architecture. They can provide effective solutions against the environmental crisis problem; yet, they are still not widely spread or utilized within architecture building constructions. These smart materials and technology must overcome number of barriers or challenges and conquer all the obstacles that act against their fully development within architecture buildings and constructions. Table 2 shows the various benefits and challenges/limitation of smart Materials.

Table 2: Benefits and Challenges of Smart Materials and Systems

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable &amp; Environmental friendly; Self-adaptable, Quick responders,</td>
<td>It’s a new technology and there is limited knowledge about these smart</td>
</tr>
<tr>
<td>Self-sensing memory and Decision maker; Self-actuation, Self-auction,</td>
<td>materials; Lack of cognition, thus, fear of risk; High cost, very</td>
</tr>
<tr>
<td>Selectivity, Transiency, Immediacy, Directness; Energy efficiency &amp;</td>
<td>expensive; Smart materials are not easily available within the market;</td>
</tr>
<tr>
<td>Reduce reliance on energy, Reduce energy and material cost of</td>
<td>Very sensible materials that needs proper skills and care</td>
</tr>
<tr>
<td>building; Reliability and Durability, Better life service, Super</td>
<td>(Mohamed, 2017) (Dahiya, 2014)</td>
</tr>
<tr>
<td>strength, Tough and ductility in addition to Excellent Bandwidth; Some</td>
<td></td>
</tr>
<tr>
<td>smart materials are Self-repaired, Self-diagnosed and Self-healing</td>
<td></td>
</tr>
<tr>
<td>materials; Initial and life cycle cost competence; Aesthetic and</td>
<td></td>
</tr>
<tr>
<td>Environmental compatibility; Better control of size, weight and shape</td>
<td></td>
</tr>
<tr>
<td>since they have reduced size, weight and shape (Sadeghi, Masudifar, &amp;</td>
<td></td>
</tr>
<tr>
<td>Faizi, 2011) (Dahiya, 2014)</td>
<td></td>
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<td></td>
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</table>

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CLASSIFICATION OF SMART MATERIALS

Smart materials are engineered material that can provide a unique and beneficial response when a change happens within its ambient climatic conditions. There are a number of various kinds of classification and descriptive systems made for smart materials. Different books and various authors has classified materials based on their characteristics as Type I (property changing – intrinsic material’s response variation to different external or internal stimuli) or Type II (energy exchanging). Since smart materials change their form or property when triggered by an external chemical or physical influences, some book authors have classified materials in terms of the resulting change of the smart materials. Thus, they categorized material in terms of the one that changes form, volume, color, appearance, memorize shape, emit light, varying viscosity or materials that generate electricity. However, the most beneficial classification approach would be based on function/system proposing a classification that establish a sequential relation between materials, technologies and environments. In the book, Green Architecture Advanced Technologies and Materials by Osman Attamann, he classified smart materials in terms of the external stimuli that the smart materials respond to. He classified materials as thermo-responsive materials, light-responsive materials and Stimulus (force)-responsive materials. He also included nanomaterials apart from the classification yet included under the chapter of smart material. This is because nanomaterials are considered as novel materials with engineered molecular structure at the nanometer scale. Thus, creating “smart” materials with enhanced properties (chemical, physical and biological), functions, performance, phenomena and processes that would react and behave differently in the nanoscale size than when the same material is on a larger scale size. Smart Material’s classification method used within this paper is inspired from Green Architecture book’s classification, but the thermo-responsive category has been changed to climate\thermo-responsive material to include the materials that responds to other climatic conditions apart from only heat and temperature. However, this paper will not talk about nanomaterial since it is a very wide field of science that entails a broader research. (Addington & Schodek, 2005) (Attman, 2009) (Schumacher, Schaeffer, & Vogt, 2010)

1. Climate / Thermo-Responsive Materials

Climate / Thermo-Responsive Materials are smart materials that transform or change their properties due to a change in different environmental conditions such as temperature, heat, or other climatic factors such as humidity, moisture and so on. Major smart materials types in the Climate\Thermo-Responsive Materials category are:

A. Thermochromic

Thermochromic materials are smart materials that performs a change in color as a response to temperature differences. When the material absorbs heat, this leads up to a thermally induced chemical reaction or a phase transformation. Thus, the material’s inner-molecular structure and its consequent light reflection changes resulting in its color-changing capability. Thermochromic materials have properties that allow them to undergo a reversible change, go back to its original color, when the surrounding temperature rechanges. Thermochromic materials come in many forms but their two general types are leucodyes and thermochromic liquid crystals. The need for a precise temperature reading dictates what material to use. If an accurate temperature is desired, then the thermochromic liquid crystals should be used. This is because liquid crystal’s molecules are organized on separate layers to allow them to change their orientation if the reading in
temperature varies. The change in temperature triggers a molecular change in the crystal which affects its color reflection from light. However, when a precise temperature reading is not necessary, then leuco dyes inks or paints can be used. In architecture field, mostly thermochromic materials are utilized for interactive visual effects such as Thermochromic Windows.

B. Thermotropic

When thermotropic material receives an input of thermal energy, it alters its microstructure resulting in a phase change. As an answer to the difference in heat and temperature variations, thermotropic smart materials endure numerous property transformation which includes transmissivity, conductivity, solubility and volumetric expansion. Thermotropic materials are considered as shape changing or phase changing smart materials and are also known for their ability to reverse to its original shape state. When these materials undergo a phase change, this results in a reconfiguration of the materials structure, for example a slight notable change can happen in the materials thermal conductivity. Thus, if there is a need to reduce the heat exchange through a material, then thermotropic can be the best choice.

There are several different thermotropic systems even though they all have similar structures. These systems are hydrogels, liquid crystals, polymer films and casting resins. Hydrogels are ideal over wide temperature range, they are three-dimensional molecular structure that undergo a large volumetric expansion when it absorbs water. They can shrink or swell their volume by a factor of 1000. Thermotropic liquid crystals are like liquid and crystalline solids and are used for efficient smart windows since they can offer privacy without losing any of the incoming light. Thermoplastic polymers are used as laminates for solar panels and greenhouses or for existing windows, roof structures. Transparent casting resins are used in diverse types of glazing like in windows, roofs and façade elements.

C. Thermoelectric

Thermoelectric is the conversion of electrical energy into thermal energy or vice versa according to the principle of thermoelectric energy conversion discovered in 1821 by Peltier Seebeck. He discovered that an electric volt is generated between the two ends of a metal bar when there is a temperature difference at each end of the bar. Thus, an electrical current input on a thermoelectric material creates difference in temperature in the material’s opposite sides which produces heat engine or pump that allows thermal energy to be transferred from one section to another. The temperature difference can be used as a source for heat or as a sink for cooling. It can operate as a heat pump or electrical power generator.

Thermoelectric is constructed from multiple layers of varied materials or a series of connected metals, thus its sometimes considered as a device. Consequently, when an electric current pass through the connections the heat is transferred. As a matter of fact, these materials have the capability of transferring large quantity of heat when connected to heat absorbing device from one side and heat dispersing device on the other side.

Thermoelectric devices are considered to be reliable, durable, silent, lightweight and compact green materials since they do not contain toxic agents, chemicals or compressed gases. However, because of their low efficiency and excessive cost they are limited in their application. Even though their energy conversion efficiency is less than the conventional technologies, yet their energy potential utility is greater.

D. Shape Memory

When a thermal energy is applied, shape memory smart materials modify their shape
from rigid state to elastic state. When the stimulus is removed, the material returns to its original state without degradation since the material remembers and recalls its previous shape. A thermal energy input alters the microstructure of the material through crystalline phase change. These changes allow the material to have multiple shapes in relation to the environmental stimulus. The thermal shape memory and super elasticity phenomenon of the material, which is the ability for the material to endure enormous reversible or elastic deformations, is part of the shape memory effect.

There are two classes for shape memory material, Shape Memory Alloy (SMA) and Shape Memory Polymer (SMP), each with a different shape changing characteristics. Shape Memory Polymers shows a mechanical property loss when exposed to a change in temperature. By contrast, Shape Memory Alloy (SMA) creates a force. The bidirectional nature of SMA can be further utilized to create several or switchable outputs, letting the material to replace components composed of many parts.

(Addington & Schodek, 2005) (Attman, 2009)

2. LIGHT-RESPONSIVE MATERIALS

Light-Responsive Materials are smart materials that transform or change their properties due to a change in light. Major smart materials types in the Light-Responsive Material category are:

A. Photochromic

When exposed to light, photochromic smart materials change their ability to reflect color and consequently the change in color is relative to the amount of UV light absorption. When the material absorbs UV light, the material’s molecule’s chemical structure (light reflection) changes. The more intense the incident light, the darker the surface of the photochromic material. Photochromic materials also have reversible color reflection, which is when the light source is removed, the material change back to its clear initial condition. If it is combined with a base color, photochromic material can change from one color to another.

B. Photovoltaic

Photovoltaic is an energetic photoelectric material that produces electricity once exposed to sunlight. Thus, photovoltaic elements convert light into electrical energy. This photovoltaic effect includes the release of the negative and positive charges carries within the material’s inner atomic structure once exposed to light. The free negative carriers, known as electrons, would move throughout the material’s cell forming a new energy that can be harnessed and afterward used for electrical energy. This photovoltaic effect was recognized since the 1839 by Alexandre-Edmond Becquerel, yet, not until the 1954 that the first silicon solar cells were patented created. These solar cells consist of semiconducting materials, mostly silicon, that produces a direct current upon light exposure. Photovoltaic modules have zero emissions, function with no noise and has an expected lifespan of 20 to 30 years. Their effectiveness depends on the size, positioning and conversion efficiency which states in percentage how much of the absorbed energy has been turned or converted into electricity.

C. Photoluminescent

Photoluminescent materials captivates radiation energy from light and then switch it to radiation energy in visible light. Photoluminescence refers to a kind of luminescence that happens when an incident energy from an external light source act upon a material, then the material re-emits the light but at a lower energy level. Luminescence is the release of
light from a substance when electrons return to their original state after excitation or provocation. Thus, the material emits non-incandescent light because of a chemical action or input of external energy. In other words, photoluminescence is the light that is released from a material that has been stimulated by UV radiation. Photoluminescence materials are used in daily life in the fluorescent lamps or the exit and emergency signs that do not rely on external energy sources and require minimum maintenance. (Addington & Schodek, 2005) (Attman, 2009)

3. **Stimulus (Force)-Responsive Materials**

Stimulus (Force)-Responsive Materials are smart materials that transform or change due to a change in external stimulants, such as electricity, kinetic energy and mechanical energy. Major smart materials types in the Stimulus(Force)-Responsive Material category are:

   A. **Electrochromic**

   Because of a change in electric current, electrochromic materials endure the ability to transmit light. Electrochromic materials change their color as a response to a change in an electric field, however, its mostly used to change a glass laminates transparency. The material’s optical properties are reversible and the material can return to normal once the electric current is removed. Applying a voltage to an electrochromic material results in a chemically induced molecular change at the surface of the material, thus changing its optical property and causing it to absorb certain visible light wavelength. In this case, the material, glass, darkens. Reversing the process, the material or glass lightens back again. Therefore, they are the main choice for visual devices.

   In the field of architecture, electrochromic are primarily utilized in smart windows for its energy efficiency and its ability to provide thermal comfort since the opacity and transparency level of the smart window can be adjusted by an applied voltage. In a typical application of electrochromic window, the relative transparency and color tint can be controlled electrically. However, note that electrochromic require power to switch from one state to another and no power to remain in its original state.

   B. **Mechanochromic – Chemochromic**

   Both are color changing smart materials where mechanochromic materials change their colors because of an imposed deformation or stresses while chemochromics change their color when exposed to specific environmental conditions.

   C. **Electrostrictive - Magnetostrictive**

   As a response to electric field, electrostrictive smart material vary in size and then generates electricity when its stretched. When an electrical current is applied, or magnetic field is applied for magneto strictive, the material’s inter atomic distance changes through polarization. The change in distance changes the molecules’ energy which as a result produces elastic energy-strain. This strain deforms or alters the material shape. These materials can be used as transducers for various electric power generation applications.

   D. **Electrorheological – Magnetorheological**

   “Rheological” is a term normally used to refer to flowing matter’s property generally viscous, semifluid, or fluid materials. As an application of an electric field, or magnetic field in case of magnetorheological materials, the material’s microstructural orientation changes which results in a change in the fluid’s viscosity. These materials exhibit interesting rheological property changing nature in their viscosity, elasticity and plasticity. When an external input of electric or magnetic field is applied to the Electrorheological or Magnetorheological fluids, the viscosity of the fluid increase. When the input is removed,
the fluid’s viscosity returns to its initial state. Thus, liquid turns into solid then back again liquid as the applied field is turned on and off.

E. Electroluminescent - Chemoluminescent

Similar to photoluminescent, electroluminescent are smart materials that emit lights once subjected to an electric field or a voltage is applied. LEDs (light emitting diodes), OLEDs (organic light emitting diodes), and EL films (electroluminescent films) come from the same concept. Light emission from these smart materials can be produced from any size, color, shape or intensity. These materials emit cold light, highly durable, strong and energy efficient. Chemoluminescent smart materials emit light if subjected to a chemical reaction.

F. Piezoelectric

Piezoelectric materials generate electric current as a response to an applied mechanical stress or elastic energy (strain). Similar to electrostrictive materials, piezoelectric are bidirectional such that the inputs can be switched. An applied mechanical force on a piezoelectric material produces a deformation that in turn produces electric current, or, reciprocally, an applied electric current causes a mechanical deformation in the material which can be used to create force. This is typically known as the piezoelectric effect or phenomenon. This phenomenon is based on reversible energy conversion between mechanical and electrical forms that happen naturally in a polarized material where parts of the molecules are negatively charged and others are positively charged. The piezoelectric effect is instantaneous and piezoelectric devices are sensitive to small voltages or pressures. Energy exchanging smart materials such as piezoelectric materials can be used as sensors or transducers or they can act as actuators by passing electric current through a material to create a force. (Addington & Schodek, 2005) (Attman, 2009)

POTENTIAL OF UTILIZING SMART MATERIALS IN UAE

Weather & Climatic Condition in UAE

United Arab Emirate, UAE, has a hot arid climate with hot temperatures almost most of the year and especially during the day while its cooler in the night specially in the winter. The country is characterized by its relative elevated temperatures, scarce rainfall, humidity and bright sunshine. However, regarding the wind, the most attractive side to exploit the wind is the north-west with its high velocity. (Taleb, 2014) Abu Dhabi’s weather &climatic data are:

- **Climate**: According to Köppen-Geiger classification, which is one of the most widely used climatic classification system in the world, UAE is considered as BWh which stands for hot arid desert climate. This climate is considered dry with deficient in precipitation. (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006)
- **Temperature**: Summer in UAE extends from May to October with a temperature range from 28˚C to 36˚C with a maximum of 48˚C in July and August. While the winter in the other months has a temperature range of 17˚C to 27˚C with a minimum reaching 12.9˚C in January. (Taleb, 2014) (NCM, 2017)
- **Humidity**: In coastal areas, the average humidity level is in a range between 50% up to 60% or 70%, however, it declines sharply inland reaching an average humidity level of 45%. Relative humidity increases during the winter month and it’s the least in May. Average humidity level in Abu Dhabi, UAE, is between 52% to 69%.
- **Rain**: Most of the country is subjected to dust storms with irregular and infrequent rainfall. Average rainfall range is between 140 to 200 mm per year and June to October are considered as the driest months of the year with 0 mm of rainfall. (NCM, 2017)
- **Solar Radiation**: Solar radiation is the energy or radiation we receive from the sun. It
comes in a multiple of different forms either visible light, ultraviolet rays, heat or infrared, radio waves or x-rays. Solar radiation measurement is higher on clear sunny days and lower on cloudy days since the sun would be lower in the sky and blocked by heavy clouds. Abu Dhabi has an abundant supply of solar radiation with longest day of the year composed of 13 hours and 30 minutes of day light while the shortest day, only shorter by 3 hours, is 10:30 long. With an annual average daylight of 12 hours per day. (El Chaar & Lamont, 2010)

Climatic Design Consideration & Problems for Hot Arid Climates

In hot arid climates, there are five main sources that would cause building problems if they weren’t considered properly in building designs. These sources are:
- Elevated temperature degree
- Abundancy or high level of solar radiation or UV
- High moisture and relative humidity level
- Excessive Summer heat gain
- Winter heat loss (Divsalar, 2010)

Abu Dhabi, UAE, which is located in a hot arid climatic zone, receives almost no rain for almost six months a year, thus, it is mainly considered as very hot and dry. For this reason, the most remarkable issue regarding providing thermal comfort for building occupant within this region is cooling. Likewise, the key objectives of climatic design features in this region are:
- Building Orientation
- Provide compact building, shading and ventilation
- Reduce area and number of openings
- Usage of high thermal capacity materials
- Reducing building’s energy consumption (Sanjarifard, Zarghampour, & Shahbazi, 2014)

Permeability & Effectiveness of Implementing Smart Materials & Systems

Nowadays, sustainability calls for adaptive and responsive building envelopes that have the capability to adapt itself to the different changes of its surrounding climatic environment. There became a need for smart and intelligent technology that not only adapts to environmental needs, but also to the needs and preferences of the building’s occupant. A necessity for design and construction that forms the greatest single possible manager of its indoor environment in terms of heat, ventilation, air quality, light and sound. Recently, dynamic responsive systems in architecture has been receiving growing interest specially the material system typology. Material system is the development of a physical kinetic system from within the mechanical and structural engineering as well as material science. (Sanjarifard, Zarghampour, & Shahbazi, 2014)

In the field of architecture, smart materials now are a major area of study that is receiving a lot of attention since it provides solution and techniques that can be used to provide human thermal comfort and also lead to energy reduction and other positive consequences. Smart materials are capable of changing their shape, dimension or its energy state reversibly as a response to one or more stimuli from the surrounding external environmental influences. These stimuli can be the effect of temperature, light, humidity or moisture, pressure, voltage, electric field, magnetic field or a chemical stimulus. Smart material can offer architectural solutions for hot arid climates such as that of UAE as follow:
1. **High Thermal Capacity Materials:**
Phase changing smart materials are materials that can absorb, store and release energy in the form of latent heat. Latent heat storage is one of the most efficient and effective ways of storing thermal energy. These smart materials can exist in different physical states, solid, liquid and gas. Phase changing material absorbs energy when it is in a heating process and then as it cools down it releases the energy back to the environment. Thus, as a building material, these phase changing materials would increase thermal mass, improve heat sink and can also be used as a curtain wall. (Arjun & Hayavadana, 2014) (Sanjarifard, Zarghampour, & Shahbazi, 2014)

2. **Shading & Ventilation:**
In hot arid climate, building has excess of solar and heat gain which would outcome in high cooling demand and indoor discomfort, for this reason shading devices and sun control are among the most notable features to be implemented for energy efficient building design strategies. That's why, great attention has been given to increase shading and create natural ventilation in order to help provide a thermal comfort environment. Lots of different smart materials and systems can be used to create both ventilation and shading effect. Smart windows that have dynamic optical properties can be used as a form of building shade. These smart windows are defined as a glass that can alter its light transmission properties when a voltage, light or heat temperature is applied, thus, changing from transparent to translucent and vice versa. Its main function is to control and regulate amount of light and heat levels that goes in and out of the building glazing in accordance to the occupants needs and comfort. On the other side, ventilation mainly helps maintain a satisfactory environment within an enclosed area. It can control different environmental measures. First is temperature, smart materials can create a relief from overheating. Second is humidity, some smart material and systems can prevent fog or condensation. In addition, it can help allow daylight and thus reducing the need of artificial lighting. Finally, smart materials can dilute undesirable odors. Multiple of different smart materials and systems can provide natural ventilation. (Sanjarifard, Zarghampour, & Shahbazi, 2014) (Al Dakheel & Aoul, 2017)

3. **Lower and Reduce Openings:**
Reducing and lowering the area and number of openings within a building skin or façade in a hot arid climate is considered as a factor that can help achieve thermal comfort. Yet, today’s modern architecture calls or demands for transparent buildings that are fully glazed. Smart materials can help solve this problem by using different chromic based smart materials as glazing units or by using smart windows. (Sanjarifard, Zarghampour, & Shahbazi, 2014)

It has been visible that many smart materials have a wide area of deployment within a building’s window, wall or façade system area. However, some smart materials can also be deployed in other areas such as in lighting systems, energy systems, mechanical systems, HVAC systems, electrical systems and structural systems. Moreover, they can also offer a wide range of solutions when used as sensors or actuators within different building systems. Table 3 below maps the needs of a typical building design and how smart materials with their characteristics can be applicable to satisfy these needs.

Utilizing these different smart materials solutions within a building and its envelope can help create a modern sustainable architecture. This is because they can help in reducing the overall building’s energy consumption; provide thermal comfort while only utilizing the available renewable energies. As well as they can create time, cost and building spaces efficiency.
Table 3: Map of typical buildings need and relevant applicable smart material (Addington & Schodek, 2005)

<table>
<thead>
<tr>
<th>Building System Needs</th>
<th>Relevant Material Or System Characteristics</th>
<th>Representative Applicable Smart Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control of Solar radiation transmitting through building envelope</td>
<td>Spectral absorptivity/transmission of envelope materials</td>
<td>Suspended particle panels, Liquid crystal panels, Photochromics or electrochromics</td>
</tr>
<tr>
<td></td>
<td>Relative position of envelope material</td>
<td>Louver or Panel systems: - Exterior: radiation (light) sensors: photovoltaic, photoelectrics - Controls/actuators: SMA, electro- and magnetorestrictive</td>
</tr>
<tr>
<td>Control of Conductive heat transfer through building envelope</td>
<td>Thermal conductivity of envelope material</td>
<td>Thermotropics, phase change materials</td>
</tr>
<tr>
<td>Control of interior heat generation</td>
<td>Heat capacity of interior material</td>
<td>Phase-change materials</td>
</tr>
<tr>
<td></td>
<td>Relative location of heat source</td>
<td>Thermoelectrics</td>
</tr>
<tr>
<td>Energy delivery</td>
<td>Conversion of ambient energy to electrical energy</td>
<td>Photovoltaic, micro- and meso energy systems (thermoelectric, fuel cells)</td>
</tr>
<tr>
<td>Optimization of lighting system</td>
<td>Daylight sensing, illuminance measurements, occupancy sensing</td>
<td>Photovoltaic, photoelectrics, pyroelectrics</td>
</tr>
<tr>
<td></td>
<td>Relative size, location and source color</td>
<td>LED, electroluminescents</td>
</tr>
<tr>
<td>Optimization of HVAC system</td>
<td>Temperature sensing, humidity sensing, occupancy sensing, CO2 and chemical detection</td>
<td>Thermoelectrics, pyroelectrics, biosensors, chemical sensors, optical MEMS</td>
</tr>
<tr>
<td></td>
<td>Location of source and/or sink</td>
<td>Thermoelectrics, phase-change materials, heat pipes</td>
</tr>
<tr>
<td>Control of Structural systems</td>
<td>Stress and deformation monitoring and control, crack monitoring, vibration monitoring and control, Euler buckling control</td>
<td>Fiber-optics, piezo-electrics, electro rheologicals, magnetorheologicals, SMA</td>
</tr>
</tbody>
</table>

**Application of Smart Material in Similar Climate**

The application of smart materials advanced technology within architecture has the power to considerably enhance and improve building’s sustainability when focusing on its embedded material’s property and functions rather than it being an artifact. When using smart high technological materials in a building they can react cleverly to climatic changes and to different seasons to provide human comfort or satisfy their needs. As an example of an application of smart material used within similar climatic condition and proved its affectability is smart windows. Smart Windows, also known as dynamic tintable, is the new class of windows that promises to transform today’s technology into a new level. These smart windows can change properties, like transmission of radiation and solar factor from the solar spectrum, as a response to a change in the surrounding environmental conditions or as a response to an electric current. Application of these smart windows would lead up to a drastic reduction of energy consumption when used in full glazed buildings, thus, reducing heating, cooling and electric lighting demands. There are various techniques that would lead up to switchable windows, however, it must take into consideration a number of specific properties and factors of building’s glazing windows. The major property or factor that needs to be available in windows is transparency or its transmittance range in the visible spectrum. After that would be its durability, expected lifetime, number of cycles it can switch without degradation, switching time or the time it needs to switch 90% of its modulation range, and finally the window size, total energy consumption, operating voltage and temperature range. All of these factors are of extreme importance when considering a smart window device. (Baetens, Jelle, & Gustavsen, 2010)

One of the most widely known smart windows are electrochromic smart windows, shown in figure 1. Electrochromism, as defined earlier, is the characteristic of a device to alter its optical property, reflection and transmittance, reversibly when an external stimulus is applied and when current flows through it. Electrochromic devices or windows mostly are
made up of multiple of layers. These smart windows are energy efficient since they provide both thermal and visual comfort for the users by lowering the thermal and glare loads. It ensures better thermal comfort since at the highest dimming level sun heat is blocked and in the lowest dimming level heat can be allowed in building’s interior. In addition, it provides solar and daylight control, with light transmission in range of 10 to 55 %, even at the dimmest level still the interior remains bright. Thus, it allows the building occupant to alter their visual contact with their surrounding and daylight provision. The electric current that is used to alter the chemical reaction causing the electrochromic window to tint and darken is very little. The electric current just changes the tint state and doesn’t need to be continuously supplied to the smart window in order to maintain the tint level. Thus, an entire building powered by electrochromic windows would only equal one light bulb, which proves how very effective this technology is. In addition, it can respond dynamically by converting color, if applicable to blue, and speed as well as being durable and cost effective. Electrochromic smart windows are the most promising state-of-art technology because of its solar energy and daylight purposes. It has high visible transmittance rates, number of cycles and modulation rate. Their properties offered extreme improvement since it has been tested that an electrochromic window when compared to traditional window, would reduce 26% light energy and 20% of the cooling loads since it was tested in the hot climates of California, USA. (Baetens, Jelle, & Gustavsen, 2010) (Azens & Granqvist, 2003) (ECONTROL-Glas, 2016) (Al Dakheel & Aoul, 2017)

![Figure 1: Electrochromic Smart Window (ECONTROL-Glas, 2016)](image)

| Table 4: Matrix with distinct smart materials classification with some of their application and required climatic design consideration for UAE (By Author) |
|---------------------------------|-------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Smart Material Classification   | Smart Material Ex. Application | Building Orientation | Shading & Ventilation | Lower # & area of opening | High thermal capacity | Reduce energy consumption |
| Climate \ Thermo Responsive Materials | Thermochromic Windows | | | | | |
| | Smart thermobimetal Self - Ventilating skin: Armoured Corset & Bloom | | | | | |
| | Hygromorphic: Meteosensitive : Hygroscopic & Hygroskin | | | | | |
| Light Responsive Materials | Photoreactive | | | | | |
| | Phototropia | | | | | |
| Stimulus \ Force Responsive Materials | Smart Window | | | | | |
| | Polyvalent Wall | | | | | |
Summary of Applicability of Smart Materials & Systems in Abu Dhabi, UAE

Based on the previous analysis and literature review, Abu Dhabi in UAE lies in a hot arid climate with elevated temperature, abundance of solar radiation, high moisture and humidity level and scarce rainfall. Architecture within this region and sustainability calls for the reduction in energy consumption, which should be initially pursued through a design that is mindful of the surrounding environmental context. The design’s aim is to provide architectural solutions that exploit renewable energies to reduce heat gain in summer and heat loss in winter. This challenge of developing environmental and energy efficient buildings require the use of effective new tools. One of these innovative tools is smart materials and systems. Smart materials are novel technologies that permit having passive and adaptive facades capable of changing their configuration autonomously as a response to the changing environmental condition and without the need of power supply or external control. The wide range of various types, classification and application of smart materials and systems has great potentials to be used within the hot arid climate of UAE. Matrix at table 4 illustrates the effectiveness of implementing distinct smart materials classification and application within the required climatic design consideration for UAE. It can be analyzed that climate, light and stimulus responsive smart materials together with their different applications, when applied within Abu Dhabi’s climate, can actually fulfill the key architecture climatic consideration required for the region. Therefore, this verifies the extent of effectiveness of utilizing smart materials in Abu Dhabi, UAE.

CONCLUSION

The 21st century has been declared as a period of urgent demanding environmental threats with limited resources and rising costs of energy. However, there has been a firm resolution that sustainable architecture and energy conscious design, that responds to environmental and technological concerns, can yield dramatic gains in the long run regarding conserving energy resource, usage of renewable sources and enhanced life quality. Buildings of the 21st century must be responsive and adaptive to environmental conditions, as well as, energy efficient. The emergence of smart materials with functions and capabilities surpassing the conventional materials and adaptive behavior to external stimuli offers new possibilities for architecture design and applications. Smart materials are the new innovative design paradigm that receive, transmit or process an external stimulus then respond to it in a useful and beneficial manner. Smart material with its various classifications and types has opened new dimensions for its applicability in sustainable architecture designs. With the utilization of smart materials within UAE architecture it is possible to overcome the challenges facing buildings envelopes and its energy consumption. These materials have enormous potential to be employed in reducing the overall building’s energy consumption, providing thermal comfort, creating time and cost efficiency as well as offering dynamic forms and aesthetic while only utilizing the available renewable energies and without the usage of any external power supply.

REFERENCES


Chapter Five: Sustainable Urban Design
Outdoor thermal environment in Havana

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Abstract: Based on the Heat Island Effect, indoor environment is influenced by specific outdoor conditions in the urban context. Precedent research works carried out by the authors have intended to characterize the influence of morphology on Havana’s urban microclimate, based on a theoretical model and experimental field work, in order to find ways to improve outdoor thermal environment. The present paper presents a comparison between measured and simulated temperatures and the results from evaluating by simulation of outdoor thermal environments in some selected public spaces in Havana both before and after some transformation proposals.

Simulation were carried out with ENVI-met 4.0, and some corrections are proposed to get results that are closer to reality. The results obtained confirm the urban heat island effect and that it is possible to improve urban microclimate as well as indoor thermal environment, should some simple design principles be taken into account, when acting intervening in public spaces.

Keywords: Urban microclimate, urban heat island, outdoor thermal environment, ENVI-met simulation

Introduction

Urban Heat Island modifies microclimate and determines real outdoor temperature, which should be considered to evaluate thermal environment indoors. Several research works have been carried out during the last three decades in order to characterize and to evaluate the influence of urban morphology on microclimate, but it has been recognized that the impact of urban form on energy performance of buildings is very complex.

A theoretical model to evaluate the influence of urban form on passive and active uses of sun and wind in Havana has been proposed in previous research works (González Couret and Sánchez, 2016), and applied to evaluate selected morphological models with an intent to improve their behaviour. In order to verify the validity of the theoretical evaluation, several measurements were carried out at certain points within the evaluated urban zones, and simulations of outdoor thermal environment were also conducted at some of these points as well. With a comparison of both results (measurements and simulations), the accuracy and validity of the simulation process could be determined, amid the aim to continue evaluating the influence of urban context on outdoor temperature by simulation, since this procedure requires less time and resources. The procedure is also useful as it helps foresee the possible impacts generated by some transformations of exterior spaces on their thermal environment.

This paper presents the results of a comparison between measured and simulated temperatures within some urban spaces in Havana, in order to determine their relationship, as well a demonstration of possible improvements of outdoor thermal environment, by transforming some modifiers of morphology effects.
Materials and methods

The present research is a continuation of precedent theoretical and empirical studies. A theoretical model was developed during the first step in order to evaluate the influence of urban morphology on passive and active uses of sun and wind. Later on, measurements were carried out in formerly evaluated urbanizations, intending to verify the validity of the theoretical model. Results presented correspond to the third step of the research, when measured values were compared to the simulated ones, and also potential improvements of outdoor thermal environment were confirmed.

The precedent empirical step focused on verifying the behaviour of the variable “street”, specifically with parameters such as section, continuity and regularity of facades, with respect to theoretical evaluation. In the present step, outdoor temperature was simulated at three of the formerly measured points, located at three different urban morphologies: compact, semi compact and open, in order to compare results to verify the software’s validity. Other parameters classified as modifiers of urban geometry (vegetation and albedo) were also simulated in some case study.

The selected point for simulation in the semi compact urbanization was East oriented, with street section (W/H) = 3.11, narrow lateral corridors (less than 1.40m width) and uniform height. The one simulated in the compact zone was West oriented, the same street section (W/H) = 3.11, continue facade (no lateral corridors) and also uniform height. Finally, the point simulated in the open urban morphology was North oriented, with section between buildings (W/H) = 1.49 (no streets in open urbanizations), separated 25 m, and 5 floors height (Figure 1).

![Figure 1](image1.png)

Figure 1. Measured and simulated points in compact, semi-compact and open urban morphologies.

The software used for simulation was ENVI-met 4.0, developed by the Institute of Geography, Department of Geoinformatic, Environmental Modeling Group (University of...
Mainz) with the objective of simulating the interaction between surfaces-plants-air in an urban environment, mainly based on fluids dynamic and thermodynamic models (Bruse, M., 2009). This software has been used in numerous research during the last years (Tumini, I., 2012), which have developed validation models demonstrating the tool’s credibility to reproduce microclimatic phenomena (Alcazar, S., 2015).

Tumini, I. (2012) carried out measurements to compare with ENVI-met simulations, concluding that there is a similar behaviour between real and simulated variables. González, J. (2011) undertook simulations based on extreme values from the nearest meteorological station, and concluded that the software offers results concurrent with reality in those critical conditions, so it would therefore be good for any other day of the year. Jörg, S. (2007) recommends to collect local data for a better usage of ENVI-met data bases, adapting them to tropical environments. Alcazar, S. (2015) proved that the turbulence calculation model trends to show error with wind velocities lower than 1m/s.

Since measurements were not carried out simultaneously, the comparison to the simulated results has been made based on the difference between temperatures in the studied point and that of the meteorological station at the same moment, in such a way that real $\Delta t$ is compared to the simulated temperature value.

Since the objective was to compare behaviour of simulated temperature to those previously measured on the street, a portion of the urban context was simulated, including the street canyon and the first building on either sides. Based on the observation of building height, vegetation, materials and other components to be represented in the model, a decision was made to use a three-dimensional grid composed by 60 x 60 x 30 cells, with a dimension of 2m each on X and Y planes, and 1m on the Z axis, resulting in a model of 120 x 120 x 30 meters. However, to reserve a needed 20 m border, equivalent to 10 cells, the built model area was finally defined in 100 x 100 x 30 meters. The model includes the essential volumetric building geometry, considering brick walls and terracotta roof slabs, dark asphalt for the streets and light grey concrete for pedestrian ways. Trees were represented according to their shape and located based on what was observed onsite (Figure 2).

Simulated period was 48 hours each, on the date corresponding to the measuring period. As input climatic data, temperature and humidity values measured at the meteorological station (Casa Blanca, Havana) were used, Northwest wind direction was predominant on the station (despite the direction being modified by the urban context), with velocity of 5m/s, from onsite measurements.

From the hourly temperature maps generated by the software (Figure 3), the specific value for each measured point was taken, at 3.5 m over the floor level, coinciding to the position of the measurement equipment. Simulated temperature values were compared to precedent measurements, and as a result, it was possible to propose corrections according to morphology type and period of time. This relationship is still being verified.

Once the relationship between measurements and simulation was characterized, and demonstrated the possible use of the software, new simulations were carried out in order to explore the influence of other parameters considered as modifiers in the theoretical model. For that, some urban spaces, located in urban morphologies evaluated as not recommendable or acceptable with respect to passive use of sun during the first research step were selected. Those specific spaces were selected in order to demonstrate that it is possible to improve thermal environment with a minimum investment, which only transforms some parameters classified as modifiers of geometry.
Figure 2. Urban areas and models for simulation (compact, semi-compact and open).

Figure 3. Temperature maps (maximum and minimum) generated by ENVI-met for each urban morphology (compact, semi-compact and open).
Four sites were selected, with different scales and configurations: at the neighbourhood scale, two squares in semi compact and open urbanization and at municipal scale, two street intersections in predominantly compact urban areas. From observation and interviews, an integral diagnosis was made, identifying problems and potentialities for each case, considering not only the microclimate, but also accessibility, mobility, spatial quality and other necessities. A graphical diagnosis synthesis was taken as the basis to conceptualize spatial transformation proposals to be developed in a progressive way. A 24 hours simulation of thermal environment was developed for each space, before and after transformation, and temperatures as well as PPD and PMV were compared. To facilitate the comparison, all data obtained were collected in an Excel table, and graphics of average values were developed.

Results and discussion

Heat Island Effect
Real measured and simulated temperature values are higher than Casa Blanca meteorological station values, thus verifying the Heat Island Effect (Figure 4). However in the compact urban area, simulation generated negative values mainly at noon, due to the shadow projected by close and tall buildings, contributing to temperature reduction. Nevertheless, the lack of vegetation and predominance of built mass favour heat absorption during day time and its expulsion at night.

Figure 4. Differences between measured temperatures in each point (compact, semi-compact and open morphology), respect to Casablanca meteorological station
Compact urban zones
A correlation between hourly distribution of measured and simulated temperatures may be appreciated, with differences from 1°C to 2°C, but with some particularities for each study case. Simulation of the compact zone maintains a constant distribution with respect to measurements, but with lower temperatures (Figure 5). It is possible to estimate the average difference between both values in order to correct results in future simulations of thermal environment in compact urban zones.

![Figure 5. Measured and simulated temperatures in compact morphology.](image)

Hourly difference between real measured temperature and simulated temperature is increasing in the morning (between 7.00 and 12.00m), and so a correcting value has been estimated for that period and another value for the rest of the day. Average difference during the morning is -2.86 °C, while the rest of the day is -1.94 °C. It means that in future simulations, temperatures obtained between 7.00 am and 12.00m should be increased by 2.86 °C, and 1.94 °C should be added to results obtained for the rest of the day to better represent reality (Figure 6).

![Figure 6. Differences between measured and simulated temperatures in compact morphology.](image)

Semi-compact urban zones
Simulated values for semi compact zone, are, on the contrary, always higher than the measured ones, except during the first 8 of 48 simulated hours, hence, these first values have been ignored and correction is assumed according to the average of the other values (Figures 7 and 8). Based on the aforementioned, temperature values simulated by ENVI-met in semi compact urban zones should be reduced by 1.59 °C, which is the average difference between simulated and real temperatures.
Open urban zones

In contrast to the previous cases, values simulated for open urban zones are higher than those measured during morning and afternoon between 8.00 am and 5.00 pm, except for the first 6 of 48 simulated hours, but they are lower for the other period of time. Because of this, a decision was made to propose two correction values; one negative from 8.00 am to 5.00 pm and another one positive, for remaining hours, based on the average differences, thus ignoring the first 6 simulated hours (Figure 9 and 10). Then, in future simulations of outdoor thermal environment in open urban zones, temperature values obtained from 8.00 am to 5.00 pm should be reduced by $0.70^\circ$C, while from 6.00 pm a 7.00 am, $1.12^\circ$C should be added.

It has been demonstrated that ENVI-met generated reasonable behaviour with respect to measured values according to hourly distribution of temperatures, concluding that it is possible to use it to simulate outdoor thermal environment in warm and humid climates as Havana’s, applying recommended corrections for each urban zone and period of day.
Influence of other parameters modifying urban geometry

In spite of the main problems related to mobility, accessibility and use of urban space, all case study presented excessive, unnecessary asphalted surfaces and scarce vegetation in such a way that transformation proposal have considered the reduction of asphalted surfaces, substituting them with concrete, other pavement materials, and grass; to increase trees and to add circulation galleries connecting disarticulated buildings so as to provide shadow on squares.

All temperature maps resulting from ENVI-met before and after transforming the spaces, show reduction in temperatures, PPM and PMV. The best results are obtained in the street intersection of “10 de Octubre” municipality, with lower temperatures up to 4 °C between 3.00 pm and 5.00 pm (Figure 11), while temperature reduction on squares may be up to 2 °C in the afternoon. PPD and PMV also achieve the best conditions in the afternoon (between 4.00 pm and 6.00 pm).
Conclusions

It has been demonstrated that it is possible to simulate outdoor air temperature in Havana by ENVI-met, but in order to get results that are closer to reality, some corrections should be made, according to urban morphology and day time:

- For compact zones it is recommended that simulated values be reduced by 2.86°C from 7:00 am and 12:00 m, and by 1.94°C from 1:00 pm a 6:00 am.
- In semi compact zones, all simulated values should be reduced by 1.59°C.
- For open urban zones it is recommended that simulated values be reduced by 0.70°C between 8:00 am a 5:00 pm, and to increase by 1.12°C those values obtained from 6.00 pm to 7.00 am.

Measured and simulated values are higher than those from Casa Blanca meteorological station, verifying the Heat Island Effect. However, simulation for compact urban zone generates lower values mainly at noon.

ENVI-met simulation shows possible improvement of thermal environment in the four urban study spaces, by transforming modifier parameters such as albedo and vegetation, which are amongst the most effective and cheaper resource.

References

Revitalizing Old Neighbourhoods of Cities contributes to their Sustainability and preserves their Urban Structure and Identity: A case study from Jordan (Jabal Amman and Jabal Al-Weibdeh Neighbourhoods)

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Abstract: In recent decades, the landscape of cities has changed significantly because of urban sprawl, which is usually accompanied by many serious problems including inefficient land use, high car dependency, low density and high segregation of uses.

This paper discusses the approach of “revitalizing old cities areas” as a challenge for transformation of cities into more sustainable urban structures that aims at minimizing the problems of city’s urban sprawl. The study adopts a descriptive-case study methodology to review the revitalization future strategies on two of the old attractive areas of Amman city (Jabal Amman and Jabal Al-Weibdeh neighbourhoods) considering the UN Habitat five principles of sustainable neighbourhood planning (efficient street network, high density, mixed land-use, social mix and limited land-use specialization) that support the three key features of sustainable neighbourhoods and cities: compact, integrated and connected. Both neighbourhoods (Jabal Amman and Jabal Al-Weibdeh) have unique urban characters rooted back to the Transjordan period in the 1920s - 1940s where they were the elite residence and accommodated the political activities of Amman.

The study focuses on the role of revitalizing Amman’s old neighbourhoods through discussing the following research questions: What is the emergent overall urban structure of Amman city today? How does it affect Amman’s old neighbourhoods? What is the anticipated future for revitalizing the old neighbourhoods of the city? and how will this affect Amman’s Structure, Sustainability and Identity in general?

Finally, the study comes into its “Conclusion” by putting the strategy of “Revitalizing Old Neighbourhoods of Cities” in its local and international perspective as one way of preserving the city’s sustainability as well as its traditional and cultural identity. The study recommends expanding the project of “Amman Downtown Plan and Revitalization Strategy” to include the two adjacent old neighborhoods (Jabal Amman and Jabal Al-Weibdeh) as they are considered as influential structures in Amman’s history and heritage. The reviewed UN Habitat principles in this study could be applicable to both neighborhoods and any future implementation and application of these principles on any of the neighbourhoods could be tested in further studies.

Keywords: Jabal Amman, Jabal Al-Weibdeh, UN Habitat five principles, Urban Revitalization, Urban Identity

Introduction

Amman (the capital of the Hashemite Kingdom of Jordan– (Figure-1-left) is the economic, political and cultural centre of the country. Although Amman's history goes back to the Stone Age and was the place for one of the earliest settlements of humans, it is still considered to be a "new city". It grew bigger after becoming the capital of Jordan in the year 1921 and is still growing as a multi-layered city that is located on the undulating plateau which makes up the north-west of Jordan. The original site of the city occupied seven hills (Jabalais in Arabic) around ‘Ras el Ain’ valley (Wadi in Arabic). The original central hills of the city are, Jabal Al-Qal’a (the historical Umayyad Citadel), Jabal Amman and Jabal Al-Weibdeh (Figure-1-right).

Figure-1 (Left): Map of Jordan (Middle): Map of Amman (Right) Map of Downtown Amman by Tania Haddad
Jabal Amman (literally “Amman Hill”) was the place where many of the transformational events of the new state took place during the Trans-Jordan time (1920s) under the British supervision, the Royal Family and the politicians experienced many important events those characterized the political and social fabric of the area, particularly between 1930-1960. Jabal Al-Weibdeh took several popular names in the past, that represented the stages of its growth. Thus, in 1950s, it was called “the nationalists’ mountain” because it was the meeting point of political activists; moreover, in 1960s the foreign embassies moved to the place giving it a new name: “the Americans' quarter”.

Jabal Amman and Jabal Al Weibdeh (Figure-3) form part of the urban core neighbourhoods, they are situated close to downtown Amman “Al Balad”, where the city's street shops, fine museums, ancient constructions, monuments, and cultural sites are found. Al Balad is the oldest part of the city currently serving as a checkpoint between West and East Amman with the vast differences between both. West Amman being Jordan’s urbanised and affluent centre and East Amman being the less fortunate, impoverished part of the capital. The two sites are located at the edge of west Amman (Figure-2), they connect the west and east, Moreover, their location at the intersection of the cultural and commercial lines (spines) of the city gives them their true charm. The two neighbourhoods have a unique urban character rooted back to the Trans-Jordan period in the 1920s - 1940s where they were the elite residence and the place for political activities from which contemporary constructions expand to the west of the city by the time. Now, both old neighbourhoods became a mixture between the east and the west, as they were neglected for a decade (1990s-2000s), poverty of east Amman affected them, however, they started losing their social value waiting to be pushed to their potential by revitalizing the physical & social dimensions of both neighbourhoods in a manner that respects the community’s historic, cultural, and urban character.
Amman’s urban structure today

Like many other cities in the world, recently, Amman’s landscape has changed significantly because of urban sprawl, which is accompanied by many serious problems including inefficient land use, high car dependency, low density and high segregation of uses. (Figure-4-Left), therefore, The Greater Amman Municipality (GAM) has recently initiated a metropolitan growth strategy (MGS) master plan, scheduled for finalization in 2025 with three different future scenarios to manage and control the current sprawl as shown in (Figure-4-Right). The growth master plan concentrates on encouraging a compact urban growth to use the existing services to their full potential, promoting the transit use, improving the pedestrian movement, directing the growth of the designated expansion areas that are close to the existing urban core, as well as improving the livelihood of the existing urban core, promoting mixed land use, protecting the environmental aspects and agricultural land, and ensuring the conservation of cultural heritage including: the contemporary city heritage, the natural heritage, ancient structures, and few political and religious monuments.


Amman Institute (AI) who is responsible for studying and presenting the municipality’s projects had introduced the “Amman Downtown Plan & Revitalization Strategy” with the vision and strategy of developing “An inclusive commercially and residentially diverse city
with a historical identity” to establish a framework and a strategy for Downtown Amman development for the next 20 years and beyond by addressing the key issues and pressing problems within the downtown including: population portrait, employment, land use and zoning, built fabric and form, public realm, housing, community facilities, roads and transportation, infrastructure, heritage and environment as shown in (Figure-6).

**Methodology:**
This study complies with the third scenario of (Intensification, Densification and Expansion) that minimizes the urban envelope (built-up areas), urban sprawl, and new roads infrastructure, which results in minimizing the impacted agricultural lands accordingly. It also goes parallel to the (MGS) of Amman (Figure-5), by which Jabal Amman and Jabal Al-Weibdeh neighborhoods fall within the primary growth of the central area (developing open space, institutions and housing), and categorized as part of Amman’s heritage under conservation studies, in addition to their location adjacent to Amman Downtown revitalization area. The study adopts a descriptive methodology to review the UN Habitat five principles of sustainable neighbourhood planning (efficient street network, high density, mixed land-use, social mix and limited land-use specialization) on both neighbourhoods, these principles support the three key features of sustainable neighbourhoods and cities: compact, integrated and connected in a trial to encourage the Greater Amman Municipality (GAM) to include Jabal Amman and Jabal Al-Weibdeh within the revitalization plan of Amman Downtown.

**1- Efficient street network:**
Amman city has a unique topography of hills and valleys that defines it as a car-based city depend on streets those goes around the hills at different levels, connected with long stairways between each two levels, especially in the urban core of downtown Amman and the surrounding hills. Accordingly, the dominance of the automobile is highly reflected in the city’s network of major roads tunnels and bridges. The current transportation system is based on the road hierarchy (Expressways, arterials, collectors, local streets, etc.) serviced by the traditional modes of transportations (cars and buses).
**Jabal Amman** and **Jabal Alweibdeh** are surrounded by arterial streets which go from the inner expressway in the west into the downtown (Figure-8), Prince Muhammad and Arar Streets pass between the two neighbourhoods. All arterial streets have the traditional car and bus public transportation mode, meanwhile, both neighbourhoods will be accessible by the proposed LRT system in the future, **Jabal Amman** will be reached by the red and yellow lines, while, **Jabal Alweibdeh** will be reached by the green and yellow lines (Figure-7-Right).

Although almost 30% of Jordanians use public transport, and these are generally the relatively poor, these traditional modes witness many associated problems related to the congestion,
traffic jams, the increase of car ownership ratio, and roads capacity. However, the results are: increasing the travel time, cost, air pollution and accident risks. The future perspectives of alternative transportation modes in Amman address the public transit (Bus rapid transit system (BRT), light rail (LRT), and national railway) accompanied with increasing the existing infrastructure capacity and utilizing the intelligent transportation systems (ITS) as a promising solution to transportation system problems. The BRT will form the backbone of Amman’s transport system of the future, including regular bus services with regular schedules, but the more exciting prospect is the introduction of rail, either in the form of a metro system or the light rail system (LRT) proposed with three lines (Figure-7-Right). The system will sometimes run overground and sometimes underground due to the hilly nature of Amman. Promoting walking in pedestrian friendly streets and alleyways is one of the major sustainable and active modes of transportation within the neighbourhood as a response to environmental and health challenges, walking helps reducing traffic congestion, GHG emissions, and healthcare costs. By maintaining the basic infrastructure of the neighbourhoods and providing safe sidewalks and pedestrian crossings, the culture of walking will be revived.

2- **High density:**
Greater Amman Municipality (GAM) has issued the Development Manual of Amman Master Plan (PMU15 November 2007 -Final) adapting the strategies of Interim Growth (IGS) and High Density Mixed Use (HDMU) which implies the Corridors Intensification Strategy (CIS) of Amman as one way of achieving it. CIS is defined as setting maximum building heights along priority transportation corridors, it essentially focuses on ten major streets in Amman that are being targeted for development. The centre of attention is *Zahran street* with a corridor between the 5th and 8th circle, being called the *(Ammani Boulevard)*. *Arar street* as well as the *Airport road* are also receiving a bulk of the attention in this plan. What is appreciated is that the design respects the city human scale in a way that none of the main three corridors propose the skyscrapers but rather low-rise buildings (a mix of residential and commercial), making room for green spaces while introducing the traditional architectural influences. The area concept of Amman’s master plan regulates the private high density mixed use (HDMU) development within the public framework providing: direct access to adjacent higher-capacity roads and pedestrian routes, zoning designations for individual parcels of land, adequate on-site parking for residents and visitors, logical locations for the servicing of high-density buildings, a range of building heights and densities that allow for transition from high density to lower-density residential areas, suitable on-site public space for use by building residents that doesn’t depend on native vegetation but on those planted in private gardens or as street trees, and finally, ensuring that building massing does not block public views (from jabal to jabal, from jabals to the wadis below, and from public ways to significant public landmarks and natural features) in addition to providing community facilities (land for mosques, schools, medical facilities, public art, etc.)

*Jabal Amman* and *Jabal Al-Weibdeh* have medium population density according to the statistics of 2015 (Figure-9), *Jabal Amman* located in *Zahran district* of 7,791.96 people/sq.km population density and *Jabal Alweibdeh* is part of *Al Abdali district* of 11,022.2 people/sq.km density. Although, they both will make use of their location close to the planned High-Density Development zones and the Intensification Corridors of Amman in the future, but there still a chance of intensifying the two neighbourhoods at a short-term plan by adding a new layer of contemporary architecture that respects the traditional heritage of them which is mostly
preserved until now. Existing buildings in both neighbourhoods were kept in peace without horizontal extensions or vertical expansions allowing the open space between them to let the neighbourhood breath and keep it at its human scale. Streets width and the lack of parking lots prevent heavy traffic in the area. Therefore, providing parking areas in some of the vacant lands distributed in the neighbourhoods will encourage people to live and invest within a walking distance.

Figure-9 (Left): Urban Density in Amman based on the population distribution on Amman’s districts - 2015
(Middle) Location within Amman’s Districts (Right): City model – Downtown Amman

Figure-10 (Left): Sha’ban Street (Middle): Topography of the site allows for medium density and offers open spaces and public views (Right): Stairways connecting the different parallel streets at steep slopes of topography

The two neighbourhoods witness simple individual trials of intensification and investments in new projects with different activities at the time, represented by building new constructions in vacant lands (urban infill projects), Wild Jordan in Jabal Amman (Figure -11-left) and La Locanda Boutique Hotel in Jabal AlWebdieh (Figure-11-right) are good examples.

Figure-11 (Left): The Royal Society for the Conservation of Nature (RSCN) - Wild Jordan16*Jabal Amman (Right): La Locanda Boutique Hotel, Jabal Al Weibdeh, Amman

3- **Mixed land-use:**
The current distribution of functions in Amman emphasizes the intensification of daily activities (commercial, institutional, educational, etc.) in the centre around the uphill
residential neighbourhoods and the industrial activities away in uninhabited areas (Figure-11-left).

The corridor intensification strategy (CIS) addresses four categories of mixed use development along the priority corridors indicated on the Corridor Concept Plans (Figure-11-right); mixed use residential, mixed use residential with commercial, mixed use commercial and mixed-use office. open spaces are also planned to constitute ‘green areas’ including parks (jabal parks, wadi parks, stair parks, trails/paths), sports fields, buffer strips, public gardens / landscaping, and civic monuments. roads, service alleys, public paths and stairways are designed, in addition to car and bus lanes, the reserves contain space for landscaping, sidewalks, and transit facilities.

The location of both neighbourhoods will make them accessible for people who will live and work in the planned (HDMU) developments of the city. Jabal Alweibdeh is connected to AlAbdali mixed use Development through Sulayman AlNabulsi Street while Jabal Amman overlooks Abdoun Corridor along Abdoun Valley and included as well in the Downtown Amman Development study illustrated in (Figure-6) with goals of housing, employment, retail, art and entertainment, tourism support, and community engagement through a policy of creating a ‘pedestrian priority’ environment.

Jabal Amman is a mixed-use neighbourhood (Figure-13) accommodates hotels (Jordan Intercontinental, Hayatt, La Royal), hospitals, schools, mosques, churches, commercial companies, British Council, formal activates (embassies and governmental offices) and a mixed-use complex (Zara complex), in addition to the residential heritage zone at both sides of rainbow street which became recently a cultural hub after renovating some houses and re-using them for different activities (Art Galleries, shops, cafes and restaurants, Institutional non-profit public activities). Different organizations are investing in the neighbourhood, the school of Architecture and Built Environment (SABE) at German Jordan University (GJU) moved to the site, it is using one of the old buildings (Darat Othman Bdeir) after renovating it, Design Institute Amman (DIA) and Jabal Amman Residence Association (JARA Information Centre and JARA Street Market during Summer time), in addition to many other institutions (Royal Film Commission, Jordan Valley foundation, Jordan Shop, Wild Jordan, etc.)

Jabal Al Weibdeh neighbourhood is located within Al Abdali district, one of the oldest parts of the city and contains several important religious and civic buildings. The Palace of Justice, Ministry of Education, King Abdullah I Mosque, Church of the Annunciation, and the Coptic Patriarchate are all located on Sulayman Al-Nabulsi Street (Figure- 14). The area underwent a radical change in the past years to be the new downtown for the city of Amman. The massive mixed-used development project of Al Abdali consists of residential and commercial buildings,
changes were also made to the roads network surrounding the project to include the construction of the Abdali Bridge that connects the project with all parts of the city.

The residential area of Jabal Al Weibdeh surround Paris Circle -which was named by the French Embassy and serves as a gateway to the area- flanked by small shops, and cafés distribute among the grand villas on its side streets (Ash-Shari’a College St. and other streets).

Figure-13: (Left) “Land Use & Zoning Strategy” (Right) “Built Form & Character Strategy” prepared by Amman

Figure-14: (Left): Jabal Al Weibdeh neighbourhood connected to Al Abdali central business district, Abdali mall, Palace of Justice, King Abdullah I Mosque and the Jordan Parliament through Sulyman AlNabulsi St.

4- Social mix: Jordan plays a moderating role in middle east affairs surrounded by Palestine, Lebanon, Syria, Iraq, and Saudi Arabia, this role is reflected in Amman’s social mix. Jordanians accounting for 69.4% of the total population while Non-Jordanians constitute 30.6% of them, about half of them are Syrians, others are Palestinians, Egyptians, Iraqi, Yemeni and Libyans. The Population of Amman has exceeded four million counts for 42% of the Kingdom’s population. 38.63% of the Jordanians and 49.78% of the non-Jordanians live in Amman. (the General Population and Housing Census 2015)

Jabal Amman and Jabal Alweibdeh were settled after declaring the capital of Transjordan in 1923. Communities from different cities and nations of various religious and social
backgrounds and ethnic origins lived next to each other and formulated social relationships. They brought their various cuisines, traditions and customs, Armenians, Italians, British, Syrians, Palestinians, Circassians, Jordanians, Kurds, Hijazis, Saltis and Nebulises met there. The neighbourhoods became the residence of royalty, wealthy families, business men, army officers, and politicians. This blend of nationalities reflected on the architectural style, notably, some villas from the late 1920s -1940s built in Jabal Amman (Figure-15) and others built in Jabal Al Weibdeh (Figure-16) have either the Lebanese or the Damascus style.

![Figure-15: Examples of the notable architecture style of Jabal Amman (Rainbow Street Neighbourhood)](image)

After achieving the full independency in 1946. Amman spread west, the 1st Circle was built, and Jabal Amman became a primary east-west artery for the quickly expanding city. By the 1970s, a process of gradual decline began to affect that area, many families moved to the newer neighbourhoods leaving its older buildings in peace during the 1970s and 1980s. Today, Both Jabal Amman and Jabal Al Weibdeh witness a revitalization process becoming two hubs for art and culture, their old buildings and beautiful architecture remain as centres of attraction for the people of the city, they form a refuge from the chaos of modern Amman, some people have memories and deep feelings towards the two neighbourhoods since the childhood, others come to socialize in streets, cafes, art galleries and theatres, they enjoy different cultural, educational, and commercial activities in the old neighbourhoods.

5- **Limited land-use:**

The Ministry of Municipal Affairs prepared a comprehensive master plan designating the land use throughout the Kingdom. Jabal Amman and Jabal Al Weibdeh originally planned to have a mixed-use character. Residential, commercial-residential, commercial and governmental activities are distributed within the neighbourhood (Figure-17).

Recently, new and different activities took place either through the regeneration projects of the main liveable spines (Figure-18) of the neighbourhoods, as in “Rainbow Street Urban Regeneration Project” which was designed by the architectural firm Turath in 2005, or through renovating old houses of the neighbourhoods to be re-used by different cultural activities. For years now Jabal Amman and Jabal Al Weibdeh have been the heart of Jordan’s creative community which continues to grow each year with more artists and designers taking up residence in the neighbourhoods, opening studios, galleries, creative spaces and cafes. Both neighbourhoods are well-known now as touristic attraction areas in Amman. Annual events are organized to increase awareness to the creative work being done, giving artists and organizations the chance to display their work to the public. Souq JARA (a flea market)
along Fawzi Malouf Street in Jabal Amman and KAZDARA art walk to celebrate the thriving creative nature of Jabal Al Weibdeh are two events take place in summer time.

The urban renewal project “Rainbow Street Regeneration Project” (Figure-18-left), was constructed by GAM in 2007 with objectives to create more public spaces that are more pedestrian friendly to encourage an active public life while enhancing, protecting, and conserving Amman’s distinctive urban heritage present in the area. The Project was based on a careful design of eight urban nodes along Rainbow street in the form of small gardens and panoramic lookouts, each with a distinctive character that is emerging from existing realities and dynamics.

In such urban revitalizing developments, dwelling should be recognized as the basic element of a neighbourhood. This includes the clear definition of outdoor space for each dwelling, the relationship of buildings and streets should enable neighbours to create a safe and stable neighbourhood and should encourage interaction and community identity that respond to local traditions. And finally, the interconnected network of streets and public open space should provide a space for recreation and appropriate settings for civic buildings.

Discussion and Conclusion:
In accordance to Amman’s vision, Jabal Amman and Jabal Al Weibdeh play a major role in honouring the original splendour and spirit of the city. By maintaining and upgrading the facilities and amenities of the two Neighbourhoods, the city will maintain part of its rich heritage and cultural values, as well as its architectural landscape and tourist environment. This study would appreciate preserving the efforts and achievements of renovation and revitalization that have been done to develop Jabal Amman and Jabal AlWeibdeh neighbourhoods, and maintaining the successful remarkable collaboration between the public and private sectors in the neighbourhoods by proceeding in revitalizing the urban structure of both on a base of developing a contemporary transportation system that is fully
integrated with the pedestrian movement, rational increasing of the neighbourhoods density in a way respecting the existing urban fabric, and implementing “green” environmental standards to reduce carbon emissions, controlling the new mixed-use activities so that they don’t affect the calmness of residents and the unique cultural character of the neighbourhoods, ensuring the social mix at the levels of permanent residents, the tourists, and the public in a built environment that GAM is responsible for setting its building regulations and land use limitations to protect it from the chaotic changes and to preserve the neighbourhood’s socio-cultural and economic aspects and values as they are the key factors of any sustainable urban structure.

The study concludes that the approach of “revitalizing old cities areas” as a challenge for transformation of cities into more sustainable urban structures is applicable to Amman by achieving the UN Habitat five principles of sustainable neighbourhood planning through revitalizing the old neighbourhoods generally, Jabal Amman and Jabal Al Weibdeh specifically. Finally, the study recommends expanding the project of “Amman Downtown Plan and Revitalization Strategy” to include the two adjacent old neighborhoods (Jabal Amman and Jabal Alweibdeh) as they are considered as influential structures of Amman’s history and heritage. Meanwhile, the reviewed UN Habitat principles in this study could be applicable to both neighborhoods and any future implementation of these principles on any of the neighbourhoods could be tested in further studies.

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The Role of Open Green Spaces in Improving the Quality of life in Residential Cities - An Analytical study of public parks in Greater Cairo

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Abstract: Public parks all over the world are considered natural respirator for the cities, in Greater Cairo they play a role in enhancing the social quality of life for residents where they help them to be more connected to the city. The paper aims at examining the relationship between the quality of public parks and the social, environmental and aesthetical quality of life for residents within the residential cities. Taking into consideration users' needs including aesthetic qualities, moral objectives, social interactions, and community development, a framework associated with the help of a questionnaire is proposed as criteria for evaluating the quality of open green areas, specially public parks in Greater Cairo, these criteria derived from the literature review then analysed thoroughly by global public parks as cases study, proved being vital in improving the quality of life of existing cities. Three public parks in Cairo had been selected as cases study; The International Park, the Giza Park, and the Family Park, all located very near to residential neighbourhoods. The findings assist in indicating that public parks in Greater Cairo are unable to raise the quality of life due to many design problems and lacking of some elements that need to be added in order to gain the adequate quality and enhance quality of life of residents nearby.

Keywords: Quality of life, public parks, users' needs, residential cities

Introduction

Social quality of life is considered a major dimension in the quality of life field, for being involving many other minor dimensions such as cultural and environmental aspects, including safety and security, access and exclusion, people and what they feel about their places (Carmona, M., et al, 2010). The paper focuses on public parks as an approach for upgrading the social quality of life, trying to investigate activities and desires manipulated in public parks signifying human interaction with the environment, and thus examine the quality of life achieved. The evolution of technology put the designers in a daily challenge to fulfil the users' needs and requirements within the society, Therefore development of gardens and public parks as well as improvement of services provided is necessary in order to cope with the huge development in various areas of life, which in turn affects the needs and requirements of users. Thus, the aspects included in this investigation are based on environmental standards and users' needs in public parks. Analysing as well as examining those aspects on different local public parks helps raising the quality of life.

RESEARCH PROBLEM

The open green areas considered being social and cultural elements in the city and vital criteria for measuring the success of society. They also have a positive impact on human nature and its distinctive visual and mental image. Then the research problem could
be summarized to be quality of green areas, specially public parks is facing a great problem due to lacking many factors, related to users' needs and the aesthetical dimension affecting the parks in their physical, environmental, and educational roles towards the community raising the quality of life, not giving even the lower demand for these gardens, thus leading to lower levels of user's satisfaction and resentment for residents of neighbourhoods nearby.

RESEARCH AIM

The research aims at formulating a framework including a checklist of indicators for evaluating the quality of public parks, which in turn help in improving the social quality of life for users within the residential cities, thus improving the quality of life for the whole city.

METHODOLOGY

The research is divided into 3 parts, firstly, a critical discussion is performed based upon a comprehensive review of the literature, focusing on the quality of life definitions regarding residential cities aiming to recognize the role of open green areas in improving the quality of life of cities, as well as spotting the light on the users' needs with in the open green areas specially public parks as well as determining social and environmental quality of life indicators needed in the residential cities and specially in the open green areas as respirator to the city. Second, a full investigation to global public parks as cases believed to have an effective role in improving quality of life for users and residents in the cities as a trial to examine the indicators deduced from the literature review. Third part, selecting case studies from Greater Cairo to test and assess the indicators in order to measure the efficiency of public parks in Cairo, thus to assess the quality of life evolved.

Quality of life within residential cities

The concept of quality of life is a comprehensive and integrated concept, encompassing many environmental aspects of urbanization (Fadda and Jiron, 1999), human and social aspects that reflect people's satisfaction with their lives and communities for encompassing indicators that are very useful for decision-makers and planners to develop solutions and alternatives to issues facing society (ENVIS Center on human settlement, 2009). They are considered benchmarks to measure goals set by society (Chamber, 1994).

However there is a strong correlation between quality of life indicators and their relationship to sustainable development (Quintas and Curado, 2009). For that the essence of sustainability is the simple idea of ensuring the quality of life for all people now and for future generations (Audit Commission, 2005).

The requirements and needs of users vary from place to place in the same city (Sirgy M.J. et al, 2009). To achieve this, planners are interested in improving the quality of life for users through the quality of services such as the quality of buildings, public and recreational places, transport and communications (Marans and Stimson, 2011), quality of public facilities, attention to the needs of people with special needs, considered as the basis of the quality of urban life, such as equality, culture, customs and traditions (Carmona, M., et al, 2010).

However indicators that must be met within the residential cities to achieve quality of life vary between several fields; Urban, Environmental, Social and Economic indicators, some are objective indicators and others are subjective. The Urban indicators could be identified into; Residential Areas including availability of infrastructure as well as planning
standards and urban fabric, providing public services, transportation, open green areas as well as achieving aesthetic qualities. The Environmental indicators should be perceived in the water and air quality, waste recycling as well as the perfect management of natural resources. For the social indicators; providing education and health care is a must, also safety and security as well as providing social integration between the communities as a whole, also neighborhoods territories and public realm, in addition to controlling the spaces identified by accessibility and exclusion (Carmona, M., et al, 2010). The economic indicators could be identified in the cost of housing units as well as the cost of services provided.

The Effect of Open Green Areas on quality of life in Residential Cities

There are fundamental considerations in the planning and design of open green areas that must be observed (Dunnett, et al, 2002) such as the areas allocated to the open green areas should be commensurate with the size of the population they serve (Walder, C., 2002). The location of the open area should be appropriate for the purpose of use (Sherer, Paul M., 2003). Taking into consideration the advantage of the topography, the preservation of the public site nature (Turner, M.A., 2004), as well as the provision of recreational elements in public parks such as fountains, levelled seating areas, vistas, nodes for gathering, outdoor theatre, avenues and attractive paths (Rogers, 2004), as shown in the following figures.

![Figure 1. Paths and water features as fundamental elements in parks, Lout Plaza Gardens, Chefchaoun, Morocco. Source: the Authors, 2017](image1)

However Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Luísa Alpalhão, 2017). Open green areas play a vital role in the process of improving the sustainable development for the inhabitants of the city (Williams and Green, 2001). For example open green areas is attributed to the urban functionality such as: achieving ecological balance and influencing the mental image of the city (Mc Cord, 2003), and towards the environmental aspect, development goes to reducing pollution levels and improving air quality (Nikolopoulou, lykoudis and Kikira, 2004) (figure.2), while towards the economic aspect, taking consideration to the revivalism of the national economy and the revitalization of tourism is important (Project Ever Green, 2010), yet towards the social aspect, increasing social interaction (Dobbins, M., 2009) is a must reducing the crime rate (Moradi Daryoush, 2010) (figure.3), increasing recreational activities, improving physical health and supporting mental health as well should be taken into account (World Health Organization, 1997).
It is worth to say that open green areas are to be characterized by easy maintenance, development and renovation (Rachel Kaplan, Stephen Kaplan and Robert L.Ryan, 1998). It contains elements that respect the human scale so that would lead to full interaction as well as recreational activities such as primary and secondary seating opportunities (CABE space, 2008), usable nodes with many activities to be held in (Achmad Delianur Nasution, 2014) (figure 4), providing more than one category according to the different social classes without any conflict in their respective activities (The trust for public land, 2004), the special needs of the disabled should be adapted as well (Rogerson Robert, 1999). Finally Open green areas are vital resources for all groups of society thus respecting the needs of these different groups, would be a step for achieving the quality of life for communities. So the designer should study the basics and conditions that must be met within open green areas in order to raise their efficiency and ability to attract individuals.

Research Approach

After deducing the indicators that should be available in the open green areas specially city parks in order to reach the social, environmental, and aesthetical quality of life for users and thus for cities as a whole. The research decided to analyse global public parks that influenced quality of life for the cities they are located in, examining the availability of those indicators induced from the literature review, in order to assess to what extent those indicators impact the resulted quality of life, then again the indicators to be applied in national public parks, with the help of a scientific questionnaire designed and distributed to the users, in order to maximize the validity and reliability of the results. Three global parks and three national parks will be examined thoroughly as shown in the following.

Criteria for selecting international case studies

The research set some points as criteria for choosing the international case studies which play a vital role in analysing the national case studies, these criteria is as follows:
- The parks to be inside the residential cities
- To owe common cultural and social aspects
- To owe similar visual aspects
- The philosophical and physiological users' needs to be similar to those in the Egyptian case studies (national parks)
- The parks are approximately the same area

It is worth to say that they all suffered from full deterioration in the past and thus isolation from users, yet after adding few design modifications according to users' needs, they became attractive again to users and thus upgraded the social and aesthetical quality of life in the neighbourhood and the city as a whole.

**Global public parks towards enhancing quality of life**

Egypt socially and culturally is different than other countries. However, the fundamental needs of the users may not differ significantly in the matter of physiology and psychology therefore, it is worth to have a look on other global cases for analysis, the research selected Kowloon park in Hong Kong (figure 5), De la Butte park in Paris (figure 6), and Brookside park in Los Angeles (figure 7) to discuss the most vital elements that must be met in the parks in residential cities. The following figures demonstrate activities and thus elements to be taken into consideration.

![Figure 5. Diversity in zones and playgrounds within Kowloon Park](http://www.lcsd.gov.hk/en/parks/ktsp/contact.html)

![Figure 6. The aesthetic qualities and green areas within the Buttes Park](https://www.tripadvisor.com/Parc_des_Buttes_Chaumont-Paris.html)

![Figure 7. The use of coloured flowers in supporting the aesthetic qualities of the Brookside Park](https://www.yelp.com/biz/brookside-park-

The fundamental needs vary in the selected parks, some are vital and mandatory, and others are not, such as accessibility, facilities and services, mandatory cultural needs such as security, safety and privacy, supportive elements related to education, art and culture. The following table encounters the needs and whether they are achieved or not in the three cases study.
Table (1) Comparative Analysis of Parks (Kowloon - De la Butte - Brookside). Source: the Authors

<table>
<thead>
<tr>
<th>Users’ needs</th>
<th>Ways to achieve</th>
<th>Kowloon</th>
<th>De la Butte</th>
<th>Brookside</th>
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<td>●</td>
<td>●</td>
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<tr>
<td></td>
<td>-adequate parking spaces</td>
<td>●</td>
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<td>●</td>
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<td></td>
<td>-the park is daily opened</td>
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<td>-holding concerts and cultural events</td>
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● Existing  ○ Not Existing
Criteria for selecting national case studies

1- They are all city parks according to their areas as well as located inside the city.
2- Allocated different spaces for different categories according to users' social classes.
3- To be very close to residential neighborhoods.
4- To contain huge green areas.
5- To be accessible and not to be prevented by physical nor geographical boundaries.
6- Not a specialized park such as the fish garden, or zoo or green house gardens.

STUDY CASES

Three parks have been selected as cases study to be analysed according to the criteria shown previously; the International Park in Nasr City district, Giza Park in Embaba district, and Family Park in New Cairo district.

The International Park built in 1987 located in the east of Nasr city district, surrounded by 4 streets, one of them is a main road, easily reached by public transportation, its area 55 acre, divided into 16 parts demonstrating different cultures from all over the world as shown in figure 8.

Giza park is located in Embaba district, it is 40 acre, built in 2014, the design inspired by the vernacular rural style, including many activities such as restaurants, cafes, cinema and child theatre, it is also reachable by public transportation as shown in figure 9.

The third case study is the family park, is located on the Cairo Swez desert road, 70 acre, determined as an educational park including different recreational, scientific and cultural zones, built in 2013, not very easy to be reached by public transportation as it is located on a high way, as shown in figure 10.
<table>
<thead>
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<th>Users’ needs</th>
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<td><strong>Main facilities</strong></td>
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<td>- fountains and water features</td>
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<td>Family Park</td>
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DISCUSSION

The responses declare some efficient achievements in the parks such as the easy accessibility due to direct contact with public transportation; the gardens are open from early morning to night all days, all parks have large green areas, availability of individual and group activities for all ages, as well as community events such as birthdays and weddings. The volunteers stated that spaces for interaction and exchange of social relations are there, festivals and cultural celebrations are held, cultural and scientific seminars for health and environmental awareness are held but not in the international park, in addition to the use of biodiversity, colours and landscapes with the use of shaded areas and guiding signs in understandable languages.

Yet the non-existing features are many such as no private spaces are connected to neither electricity nor internet connection, not all the parks owe playgrounds and swimming pools, moreover lack of attention to people with special needs, lack of security and safety due to existence of abandoned areas need surveillance system as well. Lighting system is not good as well as the distribution of firefighting taps and sound system and no existence of first aid clinic, yet some volunteers stated that cleanliness and maintenance are required. No praying spaces for women as well as no nursery for children, they also objected for not allowing participation in voluntary work, design, agriculture and gardening.

Highlighting the aspects of social, cultural, environmental and aesthetical quality of life and determining their roles was the focus of this investigation in order to be an initial step for upgrading the parks, thus leading to quality of life.

Findings

Despite being tailored according to each specific park, all three parks follow the same investigation, and responses of users were almost the same towards the three parks, evaluation of the open green areas on the analytical level finds failure in essential elements in the parks just as shown in the previous discussion, as well as existing of other elements yet needed to be upgraded in order to fulfil quality of life.

It is worth to say that overall findings show attention to entertainment and awareness of existence of public parks in the cities with the collaboration of holding festivals and celebrations as well as their role in upgrading the education of children, that was clearly shown in the responses evolved from the international park and the family park.

CONCLUSION

Throughout the research there was a challenge concerning the comparison between the global public parks and the national parks, yet administering a questionnaire was the solution for overcoming this dilemma after deducing the social and environmental quality of life indicators from the literature review, emphasizing on three public parks in Greater Cairo with different activities. Yet similar characteristics enrich the study and help getting the failure in designing the public parks, as well as helping in introducing the laymen points of view towards the social quality of life; for example upgrading the social quality of life from the laymen point of view deals with the visual image of the open green areas, specially public parks in the city as well as the cultural and educational aspect that should be represented in the parks by edutainment spaces for children such as museums and workshops coupled with the concept of sustainable landscapes, increasing the size of agriculture instead of greenery, and natural water elements or recycled water instead of...
industrial water, as well as enhancing the environmental aspects as a whole starting from the ideas of recycling garbage till the renewable energy and the different ways of implementing it within the parks and the surrounding neighbourhoods too, leading to great sense of awareness to the whole community instead of only a place for recreation and amusement.

It is worth to say that the work intended to restore the right to the city by raising awareness of social, environmental and aesthetical quality of life by imposing simple additions to the existed designs, sharing the intention of transforming semi neglected public spaces to high quality ones, sharing as well the users' opinions that embed absolute needs and requirements should be fully taken into consideration. By doing so, the researchers try to dig a direct connection between the users of these public parks and the designers that should know very well the impact of these designs on the residents of the city and thus appropriating the designs to meet the needs and requirements would be a great challenge to be respected and deal with.

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Sustainable Vertical Urbanism as a design approach to change the future of hyper density cities

High Density & Not Highrise

Ahmed Ehab Abdelsalam AEH, David Nicolson Cole & Khaled Dewidar

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Abstract: This paper will mainly focus on introducing Sustainable Vertical Urbanism (SVU) as an approach for designing hybrid buildings and upgrading the public realm, making full use of the vertical dimension in hyper density cities. The article explores some more recent case studies of optimized quality density in US, Europe and Asia. The article set out to answer the questions since density is the key of sustainable urbanism, what are the drivers and different planning approaches in relation to establishing an optimal density?

The article will analyse the outcomes of three different interviews done by the Author to specialists in the field of urban design, architecture design and construction developers. The aim of these interviews to study what is the ideal density model for tomorrows sustainable cities and explores how sustainable vertical urbanism could help us to create highly liveable, economical vibrant, mixed-use and resilient neighbourhoods of the future.

Keywords: Vertical Urbanism, Vertical public realm, City Vitality, Hyper density, Mixed use, Place making, new vertical Unusual functions

Introduction

Urban density and mixed-use are the key aspects in determining sustainable vertical urbanism. Already half of the world land surface has been changed for humanity use. As more and more people live in cities, the cities have taken core stage as a key player in the future of human populations. The main challenge for cities in the future will be the integration between compactness, vitality and urban form. (Boyko CT, 2011)

The future of cities is also about diversity which requires varying urban densities for different neighbourhoods in different part of the city. The diversity of building scale and density types allows different demographic groups to choose how they would like to live at varying stages of their lives. (Rouse, 2018)

Sustainable vertical urbanism increases efficiencies in urban infrastructure and services through shorter distribution networks. Higher density cities encourage reduced transit through shorter trip lengths, since most amenities and public transport are more closely located. However, making neighbourhoods more compact and dense needs careful consideration and a process of optimization to balance potential adverse effects; higher density is beneficial at appropriate locations, but not always in every case. (Lehmann, 2016)

All urban areas have their particular social and climatic conditions as a result of complex urban microclimates, and density affects urban wind speeds. The interplay between higher density and the increased risk of the urban heat island effect (which increases cooling energy needs) must be properly researched and taken into consideration.

Higher densities require an optimization process as higher densities can create challenges for planners and designers, for instance, to avoid over-shading, over-looking, loss of daylight and the loss of privacy, which demands clever design solutions. There are a number of other arguments against high density, which include the risk of increasing traffic congestion in the area and a potential increase in noise disturbance. (Lehmann, 2016)
Case Studies

The following section describes the selected cases of new hybrid buildings in compact superblock in Singapore, USA and Europe that have introduced density each in their own way. These cases are compact and spatially complex models featuring medium to high density housing typologies. The following case studies deserves a closer look because they have successfully introduced denser housing models and tested new innovative typologies for SVU, where buildings, public spaces, urban greenery and new functions have been combined and intertwined.

**Sky Habitat**

Sky Habitat was designed by Moshe Safdie. The hybrid complex is located in the neighbourhood of Bishan, eleven kilometres to the north of Singapore central business district. The site is adjacent to mixed use retail complex, transit hub and surrounded by schools, and religious institutions. Sky Habitat is a thirty-eight-story residential hybrid complex, that explores the balance of high density living with sustainable vertical urbanism concepts of community, landscapes, gardens and daylight.

The main concept of Moshe Safdie, was to reinvent the apartment building, to rethink the paradigm of how high density urban housing is built today. The naming of the building is a reference to his extraordinary housing complex in Montreal 1967, called Habitat. (Safdie, 2015)

On the three-acre site of Sky Habitat, the traditional, conventional solution would have been to build a number of towers, two or three, to be separate extrusions as independent buildings connected by a parking and shopping podium.

In Sky Habitat, there is one continuous structure, which is perforated and permeated by large openings and cascading terraces. There are bridges that connect the structure at three different levels. There are gardens at the sky and at the ground. There are private terraces or generous balconies for the apartments. The building steps up, almost like a hill side forming one continuous matrix of urban living.

Safdie nostalgically references hill towns and villages of Provence or Italy, or the rock-cities of Cappadocia in which the scale of the individual unit or cave is perceptible. The traditional hill town appears to be made up of many individual pieces, which are clusters of houses each one with their gardens. The designer tried to achieve the more comfortable human scale, which gives individual identity within the building and in the share external space.

Three bridging sky gardens connect the two stepping towers, creating a series of interconnected streets and gardens in the air, providing areas for common recreation and social interaction. The overall mass is open and porous allowing daylight and breezes to flow within the building. The stepping geometry allows every residence multiple orientation and private outdoor spaces. (Safdie, 2015)
Building Sustainability:

“The denser you go the more challenge it is to achieve sustainability in other words what you can do in a scale of a cluster of town houses is very difficult to do as you go Forty, Fifty, sixty stories up in the air” says Safdie. The main challenge was to create a micro climate, that’s comfortable to respond with Bishan tropical hot climate. The building needs to maximize the breezes, which means that all the public spaces within the structure, should be enjoying cross ventilation. In hot tropical climate, you need to create shade and this building is also about creating shade, deep balconies which shade the façade. Solar shades on every individual window cut the sunlight from penetrating and heating the unit. The more shade you create, the less energy needed to spend in cooling down the unit and making it comfortable. (Safdie, 2015)

In Sky Habitat2@Bishan, both these ideas are taken along in a literal sense. We see more planting in the building, and more trees supported by the various terraces. The more shade Safdie creates, the more is the sense that nature climbs up onto the building and creates its own place within the structure, acting like streets in the sky, with massive open spaces, distant views, and community facilities.

At the ground plane, more than seventy percent of the site is developed into a series of lush gardens. They provide outdoor public spaces, walking paths, tennis courts and swimming pools. Two levels of parking are completely hidden by planting, so that the parking area does not dominate the view or block the sun.

The courtyard is a ventilated space, where users can enjoy going for a walk through the whole network of walkways and bridges, from one part of the complex all the way to the other end, passing by community rooms, swimming pools, gardens, sitting areas and playgrounds. Users can do that at several levels, and this can become a part of user’s daily experience. Fathers and mothers can stroll around with their children in the building. Older senior citizens who want to spend time outdoor are able to find the appropriate space that suits them best within the building. Families can enjoy the food courts nearer the ground. (Safdie, 2015)

The façade design helps to reduce the tropical heat. The two-meter cantilevered balconies, play a vital role in shading the windows, cutting down direct solar radiation. Each apartment is designed with balconies, and most of the apartments have two or three balconies. The balconies shift left and right, which gives the inhabitants a double height balcony space, and the entire façade becomes pixelated, breaking down the mega scale of hybrid building.
“The Design of Sky habitat hybrid comes at line of evolution and developments of design which we have been working for decades to bring together all these ideas of gardens, community spaces and privacy, of permeating the building with nature; all this is coming together as part of an evolution of seeking maximum level of liveability for high density urban housing” Safdie says.

**VIA57 West “Courtscraper”**

VIA57 west, introduces a new typology to New York skyscrapers, designed by BIG for the Drust organization. VIA 57W occupies a full city block between W57th and W58th street with direct views towards Hudson river park and water front. The construction started at 2011 and was completed at 2016. The thirty-two-story building has welcomed residents since May 2016. The CTBUH named VIA57 the best tall building in the Americas as part of its 2016 tall buildings award.

The site has a beautiful location on the water, but is right next to a powerplant, waste management facility, parking garage and highway on the west side of the site. “it’s a beautiful location but it’s a very sort of industrial neighborhood” says BIG. The main idea was creating an oasis in the middle of the city, so the idea became like what happens when you combine a New York skyscraper with a Copenhagen courtyard. (Warmann, 2011)

The form starts by placing the courtyard building next to the Helena57W tower, lifting up the north-east corner to four hundred sixty feet, to give Manhattan good residential density. From the highest point, it slopes downwards to maximize day light exposure to the south and the west, and also preserve the view of the river. On the north face, the windowed façade is saw-toothed to give residents a view to the Hudson River and the afternoon sunshine, with periods of morning sunshine along 58th St.
Creating this highly unusual new silhouette on the west side waterfront, like a completely distorted Copenhagen courtyard, is a major contribution to the favourable public perception of the building. The building comes all the way down towards a horizontal line at the ground on the west side, and then as it moves towards the east, it moves upwards in a vertical incline, creating a sort of south facing mountain slope, that traces the arc of the sun at the heart of it. Individual terraces are sunken in the sloping surface, creating a sort of vertical community like a mountain town in the middle of the city; a landscaped park in a courtyard lies at the centre. (Ingels, 2016)

The VIA57 ‘courtscraper’ is a hybrid between the European perimeter block and the traditional American high rise. Most of the buildings contains residential units of different sizes with cultural and commercial programs at the street level and the second floor. The lower level of the building has a strong relationship to the courtyard. The lobby is connected directly to the courtyard, that invites residents and people to the public open space. The generous amenities at VIA57 includes lounges, gym, pool, play rooms, basketball court, golf simulator and movie screening room. Most of these amenities are placed around the courtyard to create a strong visual and physical connection between exterior communal public and the interior to enhance the urban life style within the building. At the upper level, the apartments are organized on a fishbone layout, orienting rooms towards the river view. Large terraces are carved into the façade to maximize the view and light into the apartments, while ensuring privacy between the residents. (Warmann, 2011)
Markthal Rotterdam

Markthal Rotterdam is designed by MVRDV at a historical location at Binnenrotte, next to Blaak station and the largest weekly open-air market in Rotterdam. Markthal Rotterdam is the first covered market of the Netherlands that was opened in 2014. Markthal Rotterdam is a completely new concept the first building of its kind, a hybrid between Market hall and vertical housing. By using the apartments to create an arch that covers the market, a new public building emerges. Its shape, colourful interior and the height turns Market hall in to a unique spectacular icon in Rotterdam.

MVRDV won a competition organized by the city of Rotterdam for the design and construction of a market hall at Binnenrotte. The city of Rotterdam wants to extend the existing open-air market with a covered addition. According to European future rules, the open-air sale of fresh and chilled food wouldn’t be permitted anymore. Moreover, the city want to augment the number of inhabitants in the city centre, and to create more capacity services in the area.

The city demanded program housing, parking and a market hall asked for a logically fitting solution: two residential slabs with an economically constructible market hall in between. MVRDV had seen that these kinds of market designs are always dark especially in the south of Europe, as it will act as introverted building with little connection to the surrounding urban area.

MVRDV’s vision was to create a highly public open building with good accessibility to the eastern city side of the city centre. The team decided to flip the two slabs and market vertically which lead to a larger hall with two wide opening towards the city. In order to make the construction more efficient a curve was chosen, within which is fitted elevator cores and added extra retail spaces to the lower floors. (McManus, 2015)

Markthal gives an important impulse to its surrounding area, which is strong contribution to the urban economy. Markthal with its daily fresh food market, shops and apartments creates coherent and connections in the neighbourhood that reaches a new centrality. The city of Rotterdam started refurbishing Biennenrotte square after the completion of Markthal to make it more attractive.

Markthal is easily accessible by all means of public transportation as metro, bus and tram. Blaak train station is right in front of the building. In 2015 the city of Rotterdam constructed a recessed bicycle parking with space for 800 bikes. Markthal is also accessible by car, there are four underground parking levels offering 1200 parking places. (McManus, 2015)
Markthal is not only unique in its shape and size, but specially the way of different functions are combined together - the combination of an apartment building covering a food market with food shops, restaurants, supermarket and underground parking garage – mixed use of the sort that can only be found in Rotterdam. (ArchDaily, 2014)

The building needs to be as open as possible to attract people and at the same time had to be closed due to weather conditions. Markthal is a building without a back side, all sides of the building are accessible or shop windows.

Inhabitants reach their apartments through six separate entrances, leading to elevators and double helix flight stairs. Inhabitants also have storage rooms and shared bicycle rooms in the basement. Due to the curved structure, the elevator lobbies gradually shift size and location, floor by floor. At the ground floor elevators are located at the inner façade, at the top floors towards the outer façade. Each elevator hall services a maximum of four apartments and have windows to the market and large glass fronts towards the outside.

Markthal received a BREEAM ‘Very Good’ certificate. The building is connected to the city heating and a thermal storage system underneath the building which will also heat and cool a number of adjacent buildings in the surrounding area. The various functions in the building can exchange heat and cold. For the hall, itself extensive research was conducted to create a comfortable interior climate with an extremely low energy use. The hall is naturally ventilated, underneath the glass façade fresh air flows in. It rises towards the roof and leaves the hall through ventilation shafts in the roof. Half the apartments have windows to the market; these windows are triple glazed to avoid sound or smell nuisance.
Experts Interviews

Achieving sustainable vertical urbanism is a critical issue, which has many perspectives of how the community see the design of high-rise buildings, and how they see the design of current cities. These perspectives are different, from the view of urban designers, planners, architects and construction developers. This chapter will be discussing the outcomes of expert’s interviews of different fields.

The first interview was with Tim Heath, the Professor of Urban Design at the University of Nottingham, and the author of Public places - Urban Spaces book.

The second interview was with John Prevc partner at Make Architects and has been responsible for a number of high profile regeneration projects.

The third interview was with Dik Jarman an Australian lecturer, Studio 505 Director and innovative designer, with over twenty years’ experience in architectural practice and professional film making.

Tim Heath interview outcomes (Professor of Urban Design)

People’s fear about tall buildings depends on where they are in the world. In Europe, US and UK, there is still a legacy of failed projects, putting people into buildings they didn’t necessarily want to be in. People worry about the isolating exclusivity of tall buildings; they worry about access and accessibility. With the recent fire in the Grenfell tower in London, that will affect people perceptions about the safety of living in residential tall buildings.

Particularly from the social housing perspective, in the UK there is always been a tradition of people living in houses with gardens. The concept of living in apartments is still relatively new in the UK, and still a lot of people are inspired to have a home with a garden, which doesn’t equate to what they will have in most high-rise buildings. This perception is slightly different to Europe where there are already more people living in apartments and flats in the urban centers. Generally, the most permanent thing is the risk of fire and safety, that people thinking of moving to a tall building would most fear.

It’s possible to achieve new functions in to successful mixed-use developments. There are a lot of advantages to mixing uses and, getting these new functions in to tall buildings is a positive thing, especially in dense cities where land is a premium. These hybrid buildings should be highly connected to transport hubs as rail, metro and bus to reduce the reliance on private car. Mixed use tall buildings are the future, but they shouldn’t sit in isolation, as people will still use cars to get to or from them. Mixed use hybrids, need to be integrated in to a proper master plan to be a part of a city, which will help the whole city to become more sustainable.

As we are moving towards vertical mixed-use hybrids and creating public realm, urban designers should have the role to play. They should have significant impact on place-making within the building and also think about the building and its external context.

The main obstacles facing vertical urbanism are cost, affordability and planning restrictions. “we have the knowledge, skills and technology to build and design vertical
hybrids, physically it’s not an issue, its more about policy, restrictions and public perceptions”.

Form and organization of high rise buildings will affect the users and the vitality of the city. When you get different uses within the building, the way they move around the building will change quite significantly. In tall office buildings, generally between 8 and 9 am, there are a lot of people arriving, and between midday and 2 pm, there are people going out for short lunch breaks; again between 5 and 6 pm, people are leaving the building, searching for transport. Thinking about how to manage that, and how it is organized in relation to the other uses in a mixed-use development, needs to be designed carefully, to have efficient circulation, and to make people want to use that building; thinking similarly, with the public transportation infrastructure, about the impact of that building and the number of users on the infrastructure. The local transport system should be able to cope with the number of people at peak times.

There are potentials to create vertical mixed-use streets, but we need to think to its impact on existing horizontal streets. Vertical streets shouldn’t kill the existing streets, by putting people away to isolated areas; this needs to be considered carefully. Creating a fantastic vertical street and rendering the street outside dead will result in building isolation and failure. Successful mixed-use streets are the new extension of successful public vitality streets, which always starts from the ground.

John Prevc (‘Forget about height look at density’)

When you build on a quite small plot and your building is a mixed-use complex, the main challenge is achieving a good net to gross ratio, as multiple users demand their own cores and separate lobbies. Most of the different functions, generally, don’t wish to share same service cores for practical reasons, privacy and security. The biggest building planning issue will be trying to make the cores work in a slim tall building. The other concern is servicing the multiple functions of the building. The vertical services aspects are different from the ones horizontally. Horizontally we have roads along which trucks and vans come and deliver. If you think you are delivering a lot of stuff high up a building [like vertical farming or retail], it will be economically expensive. It won’t be a net space, it’s part of the gross space that [rental-wise] is thrown away [unless specialized functions have custom rental contracts]. You should be commercially clever, to try making tall buildings of multi-functional type that will work.

One of the vertically mixed-use buildings, that the MAKE company did was the Cube of Birmingham. The Cube is a multi-functional building with underground car parking, retail stores, offices, residential, hotel and at the top, there are restaurants and bar area. The variety of mixture was exceptional in any building. It’s an incredible building, and it took an incredible client to do that. The main challenge is the high level of cost and reducing the yield, as you are not selling as many square feet because of the cores and the service area.

“We as a human being, our DNA hasn’t changed in many millenniums. We are [genetically] the same people who were historically living in caves. We like to be on the Ground, we don’t mind being on a hill on the ground, as it still the ground, it gives us advantage point for security reasons, we can look over the landscape, and make sure no one is going to attack our castle.”

“It’s a culture change; we are adapting to it, but they [tall buildings] are not in a normal situation. If you ask anybody what sort of house do you like to live, generally the answer
will be a little house, with garden on the ground. So, making the vertical more like ground is a great idea but it has many challenges to be successful”.

Projects in Singapore are successful where there is green nature on the façade, on the balconies, on the roof. Spaces are given away to eco-green, because green sells. Green is something that people want to buy into, and they are prepared to pay extra money for [the lifestyle enhancement of] that green balcony and green view; vast green areas at high level are economically expensive to achieve.

The form in tall buildings has two perspectives; firstly, from the perspective of the city and its relationship with the surrounding. Secondly, from the perspective of the user and its view out of it. From the city perspective, there are too many buildings trying to assert their own identities. They just have complex forms, to be different to sell, and to satisfy the design team’s ego.

“Vertical streets are still slightly utopian here in London; in Hong Kong it is possible, as they have high level street walks, connected with shopping malls”.

There is a massive difference between tall buildings and the hyper dense environment; you can have just as many things going on. An extra square meter of plan, multiplied many times within a vertical hybrid can produce a better environment than just going taller by many storeys. In my talk with the CTBUH, it was all about vertical urbanism not just about being tall. They start to realize it’s about density not about height.

**Dik Jarman Interview outcomes**

What people most fear about tall buildings depends on different perceptions, according to their culture and habits. When we think, as an example, of British perception, it will be the sense of loss of what they already had, like losing the historic nature of London. They can be losing what London is, its low-rise significant buildings, with historic importance; the sense of loss of who we are and where we are.

The fear of hyper density is ending. Although too many people are scared of hyper dense cities, as they think that the quality of life will go down, it seems that hyper density brings a whole lot of good. Hong Kong has the smallest car ownership on the planet, and it’s one of the highest population density spots. They have a great transport system, with buses, walkways and MTR. You can get a train anywhere within a minute; the thing with trains are that there are no traffic jams. A mass-transport system is quite different from mass-driving cars. There are many benefits that comes from hyper density, which most people don’t understand. People fear a change that makes a reduction in quality of life; this may not be true if you balance to the vibrancy, efficiency, escalation and vitality which hyper density brings to the city.

Many of the modern cities now are very lonely places, with a lot of poor urban planning in the way they arrange buildings. There are many tragic stories, of people who died in their apartments and they found them a year later, because their neighbourhoods didn’t know them. There is a lack of social interaction within buildings and with the residents’ relationship with the city. That’s a failure of city planning; city planners should start bringing communities together, which could be achieved in vertical urbanism in the way of organization. The mixed-use organization should help community networks and encourage new interactions with different communities.

If you think about driving your car to your vertical home, into an underground car park, then getting a lift to your front door... that kills all the opportunities, which used to be walking...
down the street, saying hello to someone; that is the richness vertical urbanism should provide. Vertical hybrids should be actively designed, understanding spaces and the node points where people cross; that creates a place where people can sit down and take a break or rest in an open space, which will maximize the opportunities for these meetings and greetings. That’s the way form and organization can help to facilitate better.

Hybrid buildings could change people’s perception about tall buildings, if their perception is now that buildings don’t have much public space. Good architecture can change people’s perception and fear of tall buildings. That’s exactly what happened in Melbourne, where certain large buildings as the new Melbourne museum, the new Melbourne exhibition center and couple of others showed that there is really exciting new architecture around them; so public started to take interest. There is an Australian architect Fender Katsalidis who was doing tall developments, which was really interesting in its shape, materiality and lifestyle components, which people started to realize that tall buildings didn’t have to be glass office boxes, they could be great places to live.

There is a whole series of examples, where the built architecture changed people’s opinion. Then slowly, as people’s opinion changes these buildings accelerate, because the public want more of that kind of designs. You can only sell what the public want, but you have to get them to change their opinion first.

Building tall is always expensive, and there are better ways to design it. We can build very well, richly hyper dense, and height is one part of the solution. Height is not the only solution. They need to re-design as hybrid buildings, to have more flexibility with the rest of the community and be part of the city matrix.

It’s very easy to build a boxy high-rise office building. Building a quality building which has range of functions, that’s really expensive; you need a client who is ready and willing to do this for the community, like government buildings or good developers. You need developers who want to make the greenest building in the world.

Vertical hybrids need architects who have the understanding of how to design them well, as it involves a whole range of design factors. The more we do, the more we understand them. Town planning and government can get behind these factors, as vertical urbanism is important for the community and for raising the quality of life. In long term, these hybrid buildings will be the future investment.

Conclusion
When you are densifying an area that is already dense, there is a question as to whether the existing infrastructure can cope. One other challenges city face in their densification strategies is public resistance against higher densities. If SVU frame work is considered higher density will increase liveability as can be seen in cities as Singapore, Barcelona and London. Higher density living can be acceptable for residents as long as these developments provide green sky parks and urban vital spaces. (Akers,2010)

SVU design should include high tech design solutions as well as low tech alternatives. The fundamental and organizational aspects of sustainability should consider building form, structure vitality of different functions, place making, context specific issues (Climate and Culture) and passive house solutions. (Lehmann, 2016)

High Quality sustainable vertical urban design can alleviate negative perceptions of density at the metropolitan scale. Higher densities require new better housing typologies a wider range of compact housing model and innovative design solutions that integrate urban morphology.
and the quality of public spaces. Landscaping, parks, green roofs and the design of community spaces must be important elements from the outsets of each development. (Edwards, 2014) Some of today's thinking about SVU in Singapore and Sydney could translate to other cities and inform new approaches to increase the inner-city density and sustainable urban mobility. This Article set out to answer the question since density is the key to sustainable vertical urbanism what are the drivers to consider? (Lehmann, 2016)

The analysis of the case studies explained the different planning approaches and urban form influences very different density outcomes. The outcomes of expert's interviews discussed how different parameters as building scale, density, public perceptions, public space connectivity and vertical public realm can drive the outcomes of hybrid buildings, however these parameters will need to be studied more in depth and more future research is needed with consideration of local context, for a better understanding of the optimal density level.

Acknowledgment
The author wishes to thankfully acknowledge the numerous reference resources for preparing this Article; the valuable suggestions of the Conference reviewers in improving the quality of the manuscript are greatly appreciated. A special thanks to MAKE Architects and John Prevc for his time and discussion about vertical urbanism. The author would like to express his sincere gratitude’s to Prof. Tim Heath and Prof. Dik Jarman for their interviews.

References

Exploration of Neighbourhood Public Parks’ quality: Users’ perception and Utilization pattern in Nigeria

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Abstract: Neighbourhood public parks are natural environment of rural areas for users’ leisure, recreation, psychological and physical comfort. Fewer studies have explored the users’ perception, utilization pattern and quality of public parks in Nigeria. Hence, this empirical study explores the quality of neighbourhood public parks in two rural areas in South-west, Nigeria. Users’ perception and utilization pattern were studied through appropriate documentation of the influence of the physical and spatial qualities of public parks. The 200 quantitative data were collected through the use of survey questionnaires at Ikogosi cold and warm spring in Ekiti state and Olumirin waterfalls, Erin-Ijesa, South-west, Nigeria. The study’s findings established through descriptive and regression analyses of SPSS software suggest: [1] the tourists’ perceptions on environmental sustainability on Ikogosi and Olumirin parks do not vary significantly among the tourists of diverse age groups, gender, education, length of residency, and frequency of utilization [2] the recreationist’ patronage/character and well-being do not vary significantly at the two recreational parks, while significant values were seen at the two parks in response to quality/aesthetics and maintenance /cleanliness respectively. [3] Parks’ quality and aesthetics, maintenance and cleanliness, as well as safety have shown to be significant predictors of the tourists’ utilization patterns. It is recommended that both the physical and the spatial qualities of the public parks studied needed further improvement in order to enhance the tourists’ needs and expectations. Aspects of parks’ maintenance, safety and the quality are recommended to be considered in the future planning, management, and design. This paper has contributed to filling the knowledge gap in areas of human and environment relationships towards promoting parks’ environmental sustainability in Nigeria.

Keywords: Public Park; Parks’ quality; Environmental sustainability; Tourists’ utilization pattern; Nigeria

Introduction

Parks as part of the rural landscape features function as passive and active recreation, environmental benefits, and wildlife habitat providers (Soleckiav & Welchb, 1995; Cranz, 1978, 1982; Hardy, 1982). In other words, parks status could be a natural or semi-natural state and is set aside for human enjoyment as well as for the protection of wildlife or natural habitats. The ownership and maintenance of park might be by individual or local government. While features of the park usually consist of rocks, soil, water, flora and fauna and grass areas, it may also contain buildings and other artefacts such as playgrounds.

Recently, Public Park has become an area of interest among urban designer and researchers worldwide and thus remains an important feature of the physical rural environment. As part of the physical environment, Public Park is meant for all leisure seekers that require no entry or exit restriction. In this regard, Gehl & Gemozoe (2001), affirmed that public park hosts people of diverse gender, race, and age. Recent urban development drives are not only concern about planning and design of buildings and activities but it equally involves creating functional public spaces that can have a positive impact on the users. Hence, it could be stated that public park functions as a direct
influence on residents and visitors’ social activities. The typologies of parks vary in size, form and the functions, while at the same time; it could be categorized into hierarchies of neighbourhood, district and regional park space (Thompson, 2008). Common features of public parks include playgrounds, gardens, hiking, paths ways, sports field and courts, and public restrooms depending on the budget and natural features.

Appraisal of the quality impact of the park in the community depends on the rate of recreationists’ accessibility. However, the quality of public park environment can be adjudged through the levels of user’s satisfaction. At the same time, the users’ judgment of quality of public park encircled the degree of the facilities and amenities provided coupled with the standard of maintenance (Carmona et al., 2008; Ward-Thompson, 2002; Low, 2006). Bertolini and Djist (2003), reinstated that the good quality public spaces enhance the rural environmental quality. Notably, Public Park with good quality facilities and amenities attract users’ accessibility. Literature has presented a host of numerous health benefits associated with access to public parks. For instance, access to parks have been associated with better perceived general health (de Vries, 2003; Maas, 2006), reduced stress levels (Grahn & Stigdotter 2003; Nielsen 2007); reduced depression (Morita, et al., 2007) and encourage walking (Li, 2005; Giles-Corti, et. al., 2005). Moreover, there is a substantial body of evidence demonstrating that increased walking improves physical and mental health (Manson, 2002; Fritz, 2006; Murphy, 2002; Tsuji, 2003).

Recently, Public parks are often under-developed and at risk of being undervalued in the neighbourhood planning. The purpose of this present study is to comparatively explore the quality of Public Parks through users’ perception and utilization pattern of two parks in South-west, Nigeria. The aim of this study will be reached through the following objectives: (i) finding the relationship of environmental sustainability of the Ikogusi and Olumirin parks with users’ demographical backgrounds, (ii) establishment of the relationship among the various items of users’ perceptions in the Ikogusi and Olumirin parks, (iii) to explore the effect of Parks’ Quality on Utilization pattern. Hence, a strategic assessment will identify a need to rationalize existing park space in order to overcome past planning mistakes and to address access and maintenance issues.

**Issues and Statement of Problem**

Aside from the benefits derived from parks generally, Maleki, & Habibi, (2010), noted that the lack of comparative study on the interrelationships in assessing the quality of public parks is attributed to difficulties in defining, measuring, and assessing the quality of a park. Similarly, Chiesura (2004) and Popoola et al., (2016), asserts that current sustainable park indicator should take into cognizance the availability of public spaces. Public parks have been proven to fulfil the needs and expectations for the satisfaction of local residents living environment which lead to a sustainable neighbourhood. Ikogosi and Olumirin parks are tourists’ attractions centres having a common uniqueness of features known as “waterfalls”. Therefore, the two parks have long become a visiting recreation centres for local residents, and tourists across the globe. The two parks have been adjudged to be avenues and good environments to recreates, meeting friends and visitors. Thus, there is need to investigate the parks’ qualities and utilization patterns among the recreationists as a precursor to the establishment of concrete evidence towards functional Public Park, social participation and neighbourhood growth.
Background to Study

Parks’ History, Design and Location

The first parks were deer parks, land set aside for hunting by royalty and the aristocracy in medieval times. They had walls or thick hedges around them to keep game in and people out. These game preserves evolved into landscaped parks set around mansions and country houses from the sixteenth century onwards. An aesthetic of landscape design began in these stately home parks where the natural landscape was enhanced by landscape architects such as Capability Brown. As cities became crowded, the private hunting grounds became places for the public. With the Industrial revolution, parks took on a new meaning as areas set aside to preserve a sense of nature in the cities and towns.

The level of utilization of park is typically reflected in the structure and design of the park. Therefore, the park’s structure and design determines the affordance opportunities for human use (Cranz, 1978, 1982; Hardy, 1982; Schuyler, 1986). For instance, a change in recreational demands could bring about changes in the design of parks such as the construction of more facilities for active recreation (Soleckiav & Welchb, 1995). Park design could be influenced by the intended purpose and the available land features. For instance, a park intended to cater for children’s’ recreation could also include a playground. While at the other hand, a park primarily intended for adults might incorporates feature for walking paths.

The design, operation and maintenance of Public Park is usually done by government, typically on the local level, but may occasionally involve private sector. A neighborhood park should be centrally located, if possible, within its service area and should be uninterrupted by physical barriers. It should be accessible by public transportation, or low-volume residential streets. Primarily it serves residents residing within about 1/4 mile of the park, without physical or social barriers to the boundaries (Mirsch, 1995). Ease of access from the surrounding neighborhood and central location, is key concerns when selecting a new park site. The site should allow active and passive recreational purposes. As the primary aim of Visiting Park is to experience a pleasant outdoor environment, the site should exhibit some innate aesthetic qualities.

Parks’ Sustainability and Developments

Environmental sustainability is under threat, with accelerating growth in global greenhouse gas emissions and biodiversity loss. The report of the World Commission on Environment and Development (the Brundtland Commission) entitled Our Common Future (1987), had defined sustainable development as the process that “meets the needs of the present generation without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). The concept inherent in this definition led to two versions of sustainability: “strong sustainability”, which does not allow substitutability between natural capital and produced capital (either physical or human), and “weak sustainability”, which allows such sustainability.

The ability of a city to function as a place of relaxation and opportunity are often determined by various factors, which include the environmental condition of such a place. Urban planners in the 21st century have been focusing on the concept of green city and green culture has an integral part of a functional, sustainable, clean and healthy city. Thus, the challenges of the fast-growing cities will be to steer urbanization from its current, unsustainable path towards sustainable and greener cities that offer their inhabitants choice,
opportunity and hope (FAO, 2001). Therefore, the concept of the green city becomes a sustainable city planning. The concept of “green cities”, designed for resilience, self-reliance, and social, economic and environmental sustainability usually associated with urban planning in more developed countries.

It has been suggested that the building of a “green” city is equivalent to the building of sustainability (Beatley, 2012). Many countries are planning and engaged in building green cities and “eco-cities” as starting points for the building of sustainable development. Yet, it is important to understand cities’ sustainability as a broader concept which integrates social development, economic development, and environmental management. This refers to the management and investment decisions taken by municipal authorities in accordance with national authorities and institutions. The 1987 report of the World Commission on Environment and Development, also known as the Brundtland Commission, defined sustainable development as development that meets the needs of the present, without compromising the ability of future generations to meet their own needs. The report included a chapter on urban issues. In Year 1991, the United Nations Centre for Human Settlements (UNCHS) Sustainable Cities Programme attempted to define a sustainable city as where “achievements in social, economic and physical development are made to last” United Nations Human Settlements Programme (UN-Habitat, 2002, p. 6).

Rural development is critical for an integrated approach to sustainability and for reducing poverty. Ensuring wider and inclusive access to public services can reduce rural / urban inequalities, disaster risk and food insecurity, as well as strengthen networks between cities and villages. Atologbe (2002), reinstated that the need for the park has increased in order to commensurate the demand for more green areas, natural recreation, retreat, and recreational activities. Hence, an upsurge in the governmental plan towards preventive measures to mitigate the negative effect of environmental degradation through intensified conservation efforts. Recently, efforts by Nigerian Government have been geared towards environmental impact assessment (EIA), and strategic environmental assessment (SEA), in a bid to mitigate environmental impacts of developmental projects. Therefore, Government of the day has backed private sectors’ initiative to provide leisure and other recreational facilities across the major capital cities of Nigeria.

Roles and Functions of Public Parks
Public parks’ major roles include the provision of recreational opportunities and encouragement of users’ healthier lifestyle (Calson, 2001). Other functional roles of Public Park according to Love and Crompton (1999); Ulrich (1989); McPherson (2005); USGA (2007); De Vries et. al., (2003); and Godbey et. al., (2005), include the followings: [i] preservation of essential natural artifact, [ii] protection of the local flora and maintenance of parks’ ecological functions and services, [iii] enhancement of neighborhoods’ aesthetics, [iv] the economic benefit of public park could better increase the property value the real estate market, [v] attractions centers for tourists, and business men and women, [vi] public park could improve users’ health through reduction on the stress via walking, [vii] parks’ trees and vegetations could help mitigate against global warming by reducing the amount of greenhouse gases in the atmosphere, [viii] well-maintained parks promote community engagement and residents’ social interactions among individuals of all ages and ethnic backgrounds, [ix] accessibility to parks could improve the users’ quality of life, [x] Parks helps improves rural socio-economic activities and improve tourism potentials of an area, [xi] preservation of wildlife, and natural environment of parks could improve the
environmental quality of the region, empirical research has revealed the parks’ potential in promoting childhood physical activity and reductions in the prevalence of childhood obesity.

**Description of the Study sites**

The first study area is a town called Ikogosi in Ekiti State, South-west, Nigeria, hosted the Public Park that has its uniqueness of uncommon features known as “cold and warm” springs meeting at a natural V-shaped spot. Ikogosi spring water has long become a visiting recreation park for residents, tourists/visitors across the globe. The small town of Ikogosi-Ekiti in Ekiti State in Western Nigeria is situated between lofty, steep-sided and heavily wooded, north-south trending hills about 27.4 km East of Ilesha (Osun State), and about 10.5 km Southeast of Effon Alaye (Ekiti State). It is located just north of the 7° 35'N latitude and slightly west of the 5° 00’E longitude. There are a rainy season (April–October) and the dry season (November–March). Temperature ranges between 21° and 28°C with high humidity.

The Southwesterly wind and the northeast trade winds blow in the rainy and dry (Harmattan) seasons respectively. Tropical forest exists in the south, while savannah occupies the northern peripheries. Ikogosi spring resort is one of the beauties of Nigeria in terms of natural endowment. The water runs down a hilly landscape where the warm springs form a confluence with other cold springs from adjoining hills and merge into one continuous flowing stream at 70 degrees. Located in the western part of Nigeria, known as Ekiti state, Ikogosi is a small community in terms of size and population. Ikogosi has a good local natural environment combined with rich culture and history and these form the basis of what makes the community a tourist’s destination (Godfrey and Clarke, 2000).

However, it is an awesome site where two different springs flow side by side without disturbing each other: while one is cold, the other is warm and they maintain a temperature of about 38 degrees. The measurement of the whole area of the spring is about 32 hectares and it is prevented from erosion by tall evergreen trees in which these trees form a cover for relaxation of the tourists. Apart from being a resort for relaxation, it also serves as a cure for some diseases in the body. Figure 1 depicted pictures of the nature of Ikogosi warm and cold resort.

Erin Ijesha (Olumirin) in Oriade local government is a seven-step waterfall in Osun State, South-west, Nigeria. The waterfall in Figure 2 is a whole new exciting and awe-inspiring experience with nature. The waterfall is 2km off Erin Ijesha town. According to one of the custodians of the waterfall, it was discovered by a woman called Akinla, founder of Erin-Ijesha town and a granddaughter of Oduduwa, the progenitor of the Yoruba race. This was traceable to the year 1140 AD during the migration of Ife people to Erin-Ijesa. Each step of the waterfall has a flowing fountain that marks the mystical nature of the place. The waterfall is a stunning assemblage of seven unique levels, with each level providing a whole new outlook when compared to the previous level. The waterfall exudes a therapeutic ambience produced by nature.
Figure 1: Pictorial views of Ikogosi waterfall in Ekiti State, Nigeria. Source: Researchers’ field work, (2017)

Figure 2: Pictorial views of Erin Ijesa (Olumirin) falls, Osun state, Nigeria. Source: Researchers’ field work, (2017)
Methods

The scope of the study is to investigate recreationists’ perceptions of public parks quality, and their utilization pattern while visiting the Ikogosi and Olumirin parks. In this research there are three domains used, they are: (i) Respondents’ demographic characteristics and its impacts on the parks’ sustainability (ii) various items of users’ perceptions and utilization patterns, and (iii) parks’ quality. Respondents’ demographical characteristics are expected to determine their perceptions on the parks’ sustainability as positive feelings and beneficial services. This will further enhance and contributes to the quality of life and the users’ utilization in diverse ways. This study applies a quantitative research design which is an experimental research design to achieve the desired research aim and objectives.

Self-administered questionnaires were initiated by asking the respondents to complete the questionnaire themselves. For data collection, the distribution of survey questionnaire was conducted on morning, afternoon and the evening for a total number of four weekends at the case studies sites. In other words, distributions took place between Saturday, November 4, 2017, and Sunday, 26th November 2017 by using simple random sampling method. One hundred and twenty (120) questionnaires were distributed to the tourists available at each of the Ikogosi, and Olumirin parks, totalling two hundred and forty (240) questionnaires distributed in all. Out of the 240 questionnaires administered to the tourists, only 200 were retrieved and suitable for data analysis. The contents of the survey questionnaires incorporated three (3) sections namely: (i) the perception about the relationship between respondents’ characteristics and parks’ sustainability items (iii) respondents’ perceptual variables at the two parks and (iii) respondents’ views on parks’ quality and utilization patterns. Meanwhile, respondents’ responses were measured and rated on a five-point Likert scale ranging from “1” for strongly disagree, “2” for disagreed, “3” for neutral, “4” for agree and “5” for strongly agreed.

Results and Discussions

The Cronbach’s alpha of the total variables stood at 0.75. This statistic measures internal consistency reliability, which is the degree at which responses are consistent across the items within a measure. The relationships of environmental sustainable of the Ikogosi and Olumirin parks with demographical backgrounds are presented in Table 1. The results of the ANOVA indicated that the sustainability of Ikogosi and Olumirin parks do not vary significantly among the tourists of diverse age groups (Ikogosi, p=0.33; Olumirin, p=0.36). These indicated that users of all age-groups are inclined towards the sustainability of the two parks. For the mean values scores, any positive values above 1 are considered to be concurred and of positive response by the respondents. Meanwhile, any negative values below 1 are considered otherwise. The highest mean values of m=1.28 and m=2.42 were recorded by the respondents aged between 12 years and 30 years at the two parks. Both genders (male and female) respondents equally shown a positive response, while the highest mean value of m=1.23 and m=2.44 were exhibited by the female respondents. Perceptions of parks’ sustainability are established to be higher with the Bachelor / 1st degree and post Graduate respondents in both parks. This is an indication that knowledgeable respondents are more inclined to the parks’ sustainability. Similarly, length of residency (Ikogosi, p=0.32; Olumirin, p=0.84) and frequency of utilization are determinants of tourists’ perception on the sustainability of the two parks (Ikogosi, p=0.63;
Olumirin, $p=0.54$). However, a significant difference was observed among the tourists’ time of visiting the parks (Ikogosi, $p=0.04$; Olumirin, $p=0.02$), occupations (Ikogosi, $p=0.03$; Olumirin, $p=0.04$) and duration of staying at the park (Ikogosi, $p=0.04$; Olumirin, $p=0.02$).

Table 1: Relationship of respondents’ demographical backgrounds and environmental sustainability of the Ikogusi and Olumirin parks (n=200)

<table>
<thead>
<tr>
<th>Respondents’ demographical backgrounds</th>
<th>Sustainability of Ikogosi Park</th>
<th></th>
<th></th>
<th>Sustainability of Olumirin Park</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation (SD)</td>
<td>$p$</td>
<td>Mean</td>
<td>Standard Deviation (SD)</td>
</tr>
<tr>
<td>Age (Years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 years – 30 years</td>
<td>1.28</td>
<td>0.64</td>
<td>0.33</td>
<td>2.42</td>
<td>0.83</td>
</tr>
<tr>
<td>31 years and above</td>
<td>1.20</td>
<td>0.41</td>
<td>0.24</td>
<td>2.24</td>
<td>0.72</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.16</td>
<td>0.24</td>
<td>0.29</td>
<td>2.31</td>
<td>0.71</td>
</tr>
<tr>
<td>Female</td>
<td>1.23</td>
<td>0.61</td>
<td>0.24</td>
<td>2.44</td>
<td>0.75</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No education</td>
<td>1.06</td>
<td>0.24</td>
<td>0.35</td>
<td>2.99</td>
<td>1.00</td>
</tr>
<tr>
<td>High school</td>
<td>1.15</td>
<td>0.42</td>
<td>0.29</td>
<td>3.00</td>
<td>1.10</td>
</tr>
<tr>
<td>Bachelor / 1st Degree</td>
<td>1.16</td>
<td>0.45</td>
<td>0.29</td>
<td>3.02</td>
<td>1.14</td>
</tr>
<tr>
<td>Postgraduate and above</td>
<td>1.26</td>
<td>0.55</td>
<td>0.29</td>
<td>3.24</td>
<td>1.26</td>
</tr>
<tr>
<td>Length of Residency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3 years</td>
<td>1.12</td>
<td>0.41</td>
<td>0.32</td>
<td>3.21</td>
<td>1.16</td>
</tr>
<tr>
<td>4-6 years</td>
<td>1.06</td>
<td>0.12</td>
<td>0.32</td>
<td>3.31</td>
<td>1.22</td>
</tr>
<tr>
<td>7-10 years</td>
<td>1.08</td>
<td>0.29</td>
<td>0.32</td>
<td>3.18</td>
<td>1.40</td>
</tr>
<tr>
<td>11 years above</td>
<td>1.20</td>
<td>0.59</td>
<td>0.32</td>
<td>3.19</td>
<td>1.08</td>
</tr>
<tr>
<td>Frequency of Utilization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very often</td>
<td>2.17</td>
<td>0.72</td>
<td>0.63</td>
<td>1.36</td>
<td>0.86</td>
</tr>
<tr>
<td>Often</td>
<td>2.33</td>
<td>0.70</td>
<td>0.63</td>
<td>1.14</td>
<td>0.42</td>
</tr>
<tr>
<td>Sometimes</td>
<td>2.43</td>
<td>0.82</td>
<td>0.63</td>
<td>1.06</td>
<td>0.20</td>
</tr>
<tr>
<td>Rarely</td>
<td>2.51</td>
<td>0.74</td>
<td>0.63</td>
<td>1.16</td>
<td>0.24</td>
</tr>
<tr>
<td>Time of Visiting park</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morning (6am - 12 noon</td>
<td>2.16</td>
<td>0.64</td>
<td>0.04*</td>
<td>2.12</td>
<td>0.58</td>
</tr>
<tr>
<td>Afternoon (12 noon – 4 pm</td>
<td>2.35</td>
<td>0.72</td>
<td>0.04*</td>
<td>2.33</td>
<td>0.70</td>
</tr>
<tr>
<td>Evening (4 pm – 7pm</td>
<td>2.14</td>
<td>0.61</td>
<td>0.04*</td>
<td>2.10</td>
<td>0.52</td>
</tr>
<tr>
<td>Respondents’ Occupations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government employed</td>
<td>3.31</td>
<td>1.02</td>
<td>0.03*</td>
<td>2.40</td>
<td>0.62</td>
</tr>
<tr>
<td>Self employed</td>
<td>3.30</td>
<td>1.16</td>
<td>0.03*</td>
<td>2.41</td>
<td>0.70</td>
</tr>
<tr>
<td>Not employed</td>
<td>3.16</td>
<td>1.18</td>
<td>0.03*</td>
<td>2.33</td>
<td>0.81</td>
</tr>
<tr>
<td>Retired</td>
<td>3.12</td>
<td>1.18</td>
<td>0.03*</td>
<td>2.22</td>
<td>0.80</td>
</tr>
<tr>
<td>Students</td>
<td>3.39</td>
<td>1.20</td>
<td>0.03*</td>
<td>2.43</td>
<td>0.89</td>
</tr>
<tr>
<td>Others</td>
<td>3.12</td>
<td>1.15</td>
<td>0.03*</td>
<td>2.24</td>
<td>0.82</td>
</tr>
<tr>
<td>Respondents’ Duration of stay in the park</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less 15-minutes</td>
<td>2.00</td>
<td>0.60</td>
<td>0.04*</td>
<td>2.19</td>
<td>0.51</td>
</tr>
<tr>
<td>15 minutes – 30 minutes</td>
<td>2.11</td>
<td>0.61</td>
<td>0.04*</td>
<td>2.20</td>
<td>0.61</td>
</tr>
<tr>
<td>30 minutes – 1 hour</td>
<td>2.18</td>
<td>0.64</td>
<td>0.04*</td>
<td>2.18</td>
<td>0.66</td>
</tr>
<tr>
<td>1 hr and above</td>
<td>2.35</td>
<td>0.75</td>
<td>0.04*</td>
<td>2.36</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Significance level $\leq 0.05$

Results indicate that tourists’ that visit the park in the afternoon (12noon to 4 pm) has the highest perception on the park sustainability (mean value = 2.35) at Ikogosi park; which is significantly different from the recreationists that visit at the other periods of the day. The least perception on sustainability was reported by the tourists that visits in the evening (mean value=2.14) at Ikogosi park. Same perceptions were observed at Olumirin Park. Significant differences were observed by tourists’ occupations and duration of stay on
the sustainability of the two parks. The highest perception on the park sustainability was observed by the students at both parks (Ikogosi park, mean=3.39; Olumirin park, mean=2.43); which is significantly different from other tourists of diverse occupations. The highest perceptions on the park sustainability were observed the tourists that stayed more than an hour at the two parks. (Ikogosi park, mean=2.35; Olumirin park, mean=2.36); which is significantly different from other tourists that stays at different times of the day.

Analysis of variance (ANOVA) is conducted to ascertain the difference in users’ perception at the two parks of the neighbourhoods. To examine the relationships among the five perceptual variables of tourists’ patronage and character, tourists’ well-being, quality/aesthetics of the parks, and quality/aesthetics of the parks; one-way ANOVA was conducted. The results of the ANOVA in Table 2 and Figure 3 indicated that the tourists’ patronage / character in Ikogosi park (m=4.15, Sd=0.41), and Olumirin park (m=4.12, Sd=0.45) do not vary significantly at the two recreational parks with p=0.61 and p=0.81 respectively. In view of this, it could be established that tourists’ were inclined towards patronizing the parks that subsequently impacts positively on their character. The highest mean value (m=4.15) was reported by the tourists at the Ikogosi park. Similarly, non-significant values of p≥0.05 were shown by the respondents at both parks in respect to their well-being during their visitations. This is an indication that both tourists at the two parks attest to the fact that as they visit the parks and positive impacts were observed on their well-being at the end of their visits (Ikogosi park, p≥0.31; Olumirin, p≥0.21).

Table 2: Relationship among the various items of users’ perceptions in the Ikogusi and Olumirin parks (n=200)

<table>
<thead>
<tr>
<th>Respondents’ perceptual Variables</th>
<th>Ikogosi Park</th>
<th>Olumirin Park</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation (SD)</td>
</tr>
<tr>
<td>Recreationists’ patronage and character</td>
<td>4.15</td>
<td>0.41</td>
</tr>
<tr>
<td>Recreationists’ well-beings</td>
<td>3.54</td>
<td>0.73</td>
</tr>
<tr>
<td>Quality / Aesthetics of the parks</td>
<td>1.55</td>
<td>0.46</td>
</tr>
<tr>
<td>Quality / Aesthetics of the parks</td>
<td>1.54</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Significance level ≤0.05
While considering the quality/aesthetics of the parks, there were significant difference $p \leq 0.05$ in the respondents’ perception at the two parks (Ikogosi, $p \leq 0.03$; Olumirin, $p \leq 0.02$). The results imply that improvements are needed towards increasing the quality of the parks. However, the highest mean value ($m=1.74$) was recorded at Olumirin park, indicating higher attention is required in this park while compared with the Ikogosi park. In respect to the maintenance/cleanliness of the two parks, significant differences were also observed. This indicates that adequate attentions are required towards improving the quality/aesthetics and maintenance/cleanliness of the two parks. However, the highest mean was observed at Olumirin park ($m=1.64$) revealing much attention is solicited at this particular park while compared with Ikogosi park.

The result in Table 3 revealed the regression analysis indicating that as the parks’ quality increases, so also the parks’ utilization increases. Parks’ quality and aesthetics, maintenance and cleanliness, as well as safety, have shown to be significant predictors of the tourists’ utilization patterns. The overall dimensions of parks’ quality as predictors of the utilization pattern established a significant model of $p \leq 0.05$ level in which 18.2% of the variance is explained by the model.

<table>
<thead>
<tr>
<th>Dimensions of Parks’ Quality (predictor variables)</th>
<th>B</th>
<th>Beta</th>
<th>P value</th>
<th>$R^2$ value</th>
<th>Adjusted $R^2$</th>
<th>F value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landscaping (S1)</td>
<td>0.26</td>
<td>0.14</td>
<td>0.32</td>
<td>0.250</td>
<td>0.182</td>
<td>23.15</td>
</tr>
<tr>
<td>Quality / Aesthetics (S2)</td>
<td>0.21</td>
<td>0.19</td>
<td>0.01*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance / Cleanliness (S3)</td>
<td>0.32</td>
<td>0.35</td>
<td>0.04*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety (S4)</td>
<td>0.34</td>
<td>0.33</td>
<td>0.03*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significance levels $0.05$. The regression equation: $Y = 0.26 \times S1 + 0.21 \times S2 + 0.32 \times S3 + 0.34 \times S4 + 0.30$
Conclusion and Recommendation

Findings of this research are believed to add substantially to the body of knowledge in the areas of parks’ quality and sustainability especially to the rural dwellers and the tourists. Appropriate design, planning and management of the park as a tourist attractions centers were reinstated in this study in a bid to enhance parks ‘accessibility and utilization as well as tourists’ experiences. Both the residents and the tourists play a critical role in parks’ perceptions, utilizations and maintenance, depending on their socio-demographical features, cultural, and social backgrounds. In the same vein, the socio-demographic characteristics of users affect the appraisal of the parks’ sustainability levels, and sharing capability as outdoor spaces. In addition, public parks’ provision and quality are tailored towards creation of a safe, aesthetic and comfortable rural environment.

This research has affirmed that the public park attractiveness or aesthetics could also promote users frequent utilization. In other words, quality of public park is determined by the degree of the facilities and amenities provided coupled with the standard of maintenance. It could be stated that unalloyed relationship exists between the parks’ maintenance, facilities and amenities and that of parks’ quality. Meanwhile, the size and nature of activities initiated in public parks responds to the users’ sense of judgment in terms of the quality. Similarly, availability of an adequate security and safety in the parks influence the users’ perception relating to the quality and rate of accessibility. Sustainability depends on how much of the natural environment such as parks can be conserved, maintained and appreciated. Based on this study’s findings, the following are recommended:

(i) The planning, development or redevelopment of the two parks in rural communities should be given a special attention. This will further reduce the adverse effects of climate change, global warming and Green House Gas (GHG).

(ii) Adequate improvements on the two existing parks will not only save the neighbouring communities from environmental problems but also enriches users’ health and well-being.

(iii) There is a need for advocacy on the parks’ promotion and awareness. The influx of recreationist and tourists alike could improve the economic viability status of the rural dwellers.

(iv) Good accessibility and provisions of essential facilities could promote effective utilization of the two public parks in the rural communities. Hence, the patronage of these public parks is subjective to the users’ financial capability and these need to be properly considered when fixing the price for the parks’ use.

(v) There is a need for proper investment in the provisions of essential amenities, and facilities in the two public parks. Hence, the mental, emotional, and therapeutic benefits of the two parks could be more appreciated fully.

(vi) Both the State and Local Government needs to adopt public-private partnership initiatives in parks’ management in order to enhance and bring about adequate facility maintenance in Nigeria. Through this, proper maintenance of the existing parks could be achieved.

(vii) The two parks and others across the country need to be upgraded up to the global standard. Hence, inadequate facilities such as the cafeteria, power supply (electricity and generator), and security could be improved.
References


Power, Transport Strategy, and the Environment: An analysis of the environmental discourse surrounding a proposal to develop a new park-and-ride facility for Bath

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Abstract: Park-and-ride (P&R) is a transport mode change parking facility, which abstracts car passengers onto public transport at the city periphery, reducing congestion and air pollution. However, this is a contested space, with environmental arguments used both in favour of and against such developments. This study interrogates the power relationships surrounding a proposed P&R facility in Bath through discourse analysis, illustrating how organisations and individuals used the power of various environmental discourses to affect the trajectory of the development proposal. The research was based upon Foucauldian discourse analysis, also borrowing from Flyvbjerg’s phronetic planning research. The primary data source was a transcript of Bath and North East Somerset Unitary Authority’s January 2017 Cabinet meeting, whose single agenda item was to choose between two greenfield sites in the World Heritage Site setting for a new P&R. Despite expectations that transport policy would be driven by business and economic considerations, forces for environmentalism, and for preservation of Bath’s green setting, proved stronger. The council struggled to engage effectively with opponents. Campaigners waged an effective campaign through professionalism, skilled networking, and expert use of new and old media. This case study provides support for developing a collaborative and transformational approach to policy making.

Keywords: Discourse analysis, phronetic planning research, power, environment, park-and-ride

Introduction

In this paper, the sustainability of park-and-ride (P&R) as a concept is reviewed, before setting out how discourse analysis was used to interrogate power relationships behind decision-making in relation to a proposal for a P&R facility on Bathampton Meadows, Bath.

Park-and-ride in the UK

P&R’s are transport mode-change parking facilities at the city’s edge, with dedicated public transport to the centre, designed to reduce city centre congestion. The first UK facility opened in Oxford in 1973 (Elsom and Crabbe, 1996). P&R service models vary. The predominant form in Britain is a large car park with bespoke bus service, although some cities with local rail, denote station car parks as P&R; other cities use many smaller car parks.

After becoming mainstream UK transport policy, P&R gained a positive image with policy-makers, who believe it will resolve congestion and pollution, whilst raising the profile of public transport (Meek, Ison and Enoch, 2010). Its popularity amongst the car-owning public, and conspicuousness, are thought important factors in policy-makers’ enthusiasm. Motivations for implementation (Parkhurst and Meek, 2014) may include a desire to tackle congestion and air pollution; encourage commerce; simplify the transport system, where P&R sites form public transport interchange nodes; manage congestion arising from long distances within the authority’s boundaries without the need for negotiation with neighbouring authorities; or control deregulated bus services. Dijk and Montalvo (2011) surveyed policymakers in 45 European cities, finding through linear regression analysis that anticipated economic benefits, perceived demand, and organisational learning capability were factors most strongly linked with adoption of P&R by an administration.

P&R is rarely subject to rigorous post-implementation benefits realisation assessment (Parkhurst, 1996), whilst councils tend to consider only perceived local benefits, neglecting
global disbenefits such as higher CO₂ emissions (Parkhurst and Meek, 2014). It is therefore timely to examine motivations for political decision-making regarding this controversial transport solution, through a case study of Bath’s proposed eastern P&R.

**Park-and-ride within Sustainable Transport Discourse**

P&R has sometimes been promoted by government as an “essential element in holding down traffic levels” (Prescott, 1998). Goodwin et al. (1991) favoured P&R within an integrated transport strategy, proposing public transport use for the longer leg, private car the shorter, a model now known as “link-and-ride”. Its sustainability is often promoted, but concerns with the policy’s congestion-countering effectiveness, arose early and persist. Heggie (1977) found that only 57% of Oxford P&R users had previously driven to the city centre, and congestion reduction targets were unmet. In a study of Oxford and York, Parkhurst (1995) reported unchanged congestion, trip generation, and switching from sustainable modes to driving, speculating that overall mileage may have increased. Increased mileage due to P&R was then demonstrated for eight British towns (Parkhurst, 1999), and in a review of UK P&R policy (Meek, Ison and Enoch, 2008).

Meek, Ison and Enoch (2011) surveyed Cambridge P&R users, finding increased vehicle mileage per passenger. Different geographies of car-bus interchange were modelled, and P&R peripheral to the city was found to increase overall mileage, whilst link-and-ride offered reductions. Parkhurst and Meek’s (2014) review of the policy debate around P&R, similarly concluded that mode shift occurring earlier in the journey more effectively reduced overall mileage, supporting rural bus services, thus boosting both CO₂ emissions savings due to P&R, and reducing its adverse social impacts. In a study in Bath, Clayton et al. (2014) surveyed drivers parking at both P&R and in the city centre, concluding that a model of P&R using peripheral parking facilities causes substitution of the car, for more sustainable modes, for the major portion of the trip, resulting in increased car dependence. It was considered that a new eastern P&R risked increasing unsustainable travel behaviour, and reducing support for traditional public transport. Link-and-ride was proposed for the east of Bath, as part of a transport policy focused on modal integration.

In summary, P&R can only reduce carbon emissions where there is a longer public transport leg and shorter private leg, and where it is part of an integrated transport package, incorporating methods both of curbing car travel, and of boosting public transport.

**Theoretical Approach**

**Discourse analysis**

The research took a social constructivist discourse approach, drawing on Dryzek’s (2012) environmental discourse coalitions for analysis of themes and storylines, and with questions from phronetic planning research (Flyvbjerg, 2004) helping to guide the study. Discourse analysis supports study of environmental politics through investigation of organisational structures, power, and knowledge (Hajer, 1997), illuminating both how discourses curtail the range of environmental policy ideas proposed, and the bias inherent in particular discourses. It is particularly effective at answering “how” and “why” questions concerning political decision-making. The technique provides elucidation of power relationships, and of mechanisms for political decisions and actions, aiming to establish why one interpretation of the political situation gains dominance, or is black-boxed (Hajer, 1997). In black-boxing, the discourse that has become dominant no longer seems to require justification, whilst other discourses lose influence.
In a Foucauldian discourse analysis, communication is seen as influencing social change, and vice versa (Sharp and Richardson, 2001), but the technique crucially also considers underlying ideas, concepts and ideologies uniting actors using a discourse; and conceives of social change as the result of competition between different ideologies, as represented in the stories actors tell. In Foucauldian analysis, truth is not attributed to discourses: rather, who attributes what truth, how, and to which arguments, is studied, to illustrate the process and struggles during, and consequences of, policy formation (Sharp and Richardson, 2001). This school is deeply embedded in the historical context, aiming to build as rich a picture as possible of both discourses and actions, hidden and explicit, in context.

Hajer (1997) and Flyvbjerg (1998), key influences of this study, used the Foucauldian definition, viewing the spoken word as the manifestation of continuous power struggles occurring behind the scenes between different groups, or discourse coalitions. This study focuses on power relationships between coalitions, basing analysis closely on a transcript of one meeting, set in its historical context. Truth is conceived as in the eye of the beholder, and actions taken by parties in the struggle are closely studied. A possible deficiency of Foucauldian analysis, that it makes no recommendation regarding policy (Sharp and Richardson, 2001), is overcome here by the use of phronetic planning research (Flyvbjerg, 2004), a methodology focused on undertaking research of importance in the real world through four key questions: Where are we going with planning?; Who gains and who loses, and by which mechanisms of power?; Is this development desirable?; What, if anything, should we do about it?

Choice of case study

This case study investigates the power dynamics and motivations of actors on opposing sides of the debate concerning construction of Bath’s proposed eastern P&R. The case is noteworthy in that the proposal has persisted for forty years, without coming to fruition. Additionally, Bath’s status as the UK’s only World Heritage City, and its corresponding difficulty accommodating modern traffic, with the congestion and air pollution generated, offer potential for world leadership in sustainable transport solutions for historic cities. During the emerging stand-off between council and campaigners, the council’s determination to build, in line with the business community’s wishes, faced with resilience and professionalism by environmental campaigners, represented a tension point meriting research (Flyvbjerg, Landman and Schram, 2012). The study concerns the period from Bath and North East Somerset’s (B&NES’) unitary authority elections in May 2015, to July 2017, when the eastern P&R proposal was abandoned. A huge volume of discourse was publicly available, generated by both sides. It was decided to focus on this material, giving an objective view of real-life actions showing values-in-use, rather than espoused values that would have been revealed through interviews (Tracy, 2012).

Data sources

The primary data source was the B&NES special Cabinet meeting of 25th January 2017 (B&NES Council, 2017b, 2017a), with a single agenda item, ostensibly to choose between Sites B and F on Bathampton Meadows (Figure 1). A limited number of self-selecting, pre-booked public speakers and Councillors, from both sides of the debate, spoke. It was representative, in that those from both sides had equal opportunity to attend. The self-selection of attenders, along with topics they chose to cover, all inform the study. 500 people were said to have protested outside (Crawley, 2017). A verbatim transcript (Warren, 2017) was created from a webcast of the meeting on the council’s website, the primary data source. In this study, discourses
from the meeting are put into the context of council’s current and historical transport policy, to build a clear understanding of the context of discourses and actions by both sides (Sharp and Richardson, 2001). Historical documents were consulted, some online, some in hard copy at the B&NES Local Studies Archive, and Bath Preservation Trust Archive, providing insight into the council’s thinking in earlier decades.

Figure 1: Sites 7 (Lambridge), A, and B and F (on Bathampton Meadows) for the proposed eastern P&R (Powell, 2017), annotated with additional sites by Warren (2018)

Case Study Introduction

Bath and North-East Somerset Context

Carbon emissions and air pollution targets and performance

B&NES, a unitary authority in southwest England, comprises the World Heritage City of Bath, and, predominantly to its west, the rural constituency of North-East Somerset. B&NES set a total CO₂ emissions reduction target of “45% by 2029”, with a planned per capita road traffic CO₂ emissions reduction of 10% against 2006 levels, by 2020 (B&NES Council, 2016). An 8% reduction was achieved between 2005 and 2015 (DBEIS, 2017), with all emissions influenceable by the authority falling by 29% over the same period. Transport thus forms an increasing percentage of the total, 31% in 2015 (Figures 2 and 3). The authority is also under pressure to tackle dangerous levels of air pollution (B&NES Council, 2017c), so an effective method of countering traffic emissions is urgently required. From 2009 to 2017, a key plank of the council’s proposed programme to reduce traffic emissions was a new P&R facility on Bathampton Meadows (B&NES Council, 2017c).
Figure 2: CO₂ emission estimates for B&NES by sector (kt). Graph (Warren, 2018) with DBEIS data (DBEIS, 2017)

Figure 3: CO₂ emissions estimates for B&NES by sector (kt). Graphs (Warren, 2018) based on DBEIS data (DBEIS, 2017). Road transport has increased from 24 to 31% of total.

Setting of proposed park-and-ride

The site of the proposed P&R, historic Bathampton Meadows, lies 3km north-east of Bath Abbey, in the River Avon flood plain (Figure 1). South of the river, overlooked by hills from all sides, the Meadows, owned by B&NES, have long been in agricultural use, and are currently grazed. In 1994, they were the site of a sustained battle between the Department for Transport, Avon County Council, and campaigners, over construction of the A4 and A46 Batheaston and Swainswick bypasses, the dual carriageways in green in Figure 1 (Wall, 1999). Prior to 2015, Site 7 (Figure 1) was seriously considered for a P&R facility (Jamieson MacKay & Partners, 1976), finally being abandoned due to flood risk in 2006 (B&NES Council, 2017c).

Emerging Coalitions

The park-and-rider coalition comprised eight Conservative councillors, most of whom represented rural western wards far distant from the proposed site, and six were Cabinet members, including the Council Leader and Transport Lead. They were joined in coalition by the Federation of Bath Residents’ Associations (FOBRA), claiming to speak for 4,500 city centre residents, the business lobby including the Executive Director of Bath Chamber of Commerce, and a representative of the South West Network of Bus Users UK. There were internal contradictions within this coalition: although FOBRA and the business lobby were allies in desiring increased P&R capacity, FOBRA hoped for reduced central parking to ease central congestion and pollution, whilst the economic gains envisaged by business depended upon the P&R providing additional parking. These differences went unacknowledged, presumably either invisible to coalition members, or deferred to the future. Despite formal
consultation, this coalition was perceived by campaigners as exclusive of other groupings and organisations, and consequently as excluding alternative discourses.

The diverse anti-park-and-rider grouping consisted of all three local councillors, Conservative and Liberal Democrat, for Bathavon North Ward, containing the P&R site, opposition Liberal Democrat and Labour councillors, conservation organisations the National Trust and Bath Preservation Trust, parish councils and residents’ associations for affected communities, and individuals.

**Park-and-ride storylines**

Of park-and-rider storylines, the most frequently mentioned at the meeting concerned economic growth, whilst congestion and pollution reduction arose less frequently, in contrast to the written background information (B&NES Council, 2017c), which tended to emphasise traffic reduction and its knock-on benefits. Other key storylines used at the meeting, included a firm belief in the efficacy, popularity and sustainability of P&R as a policy choice ('black-boxed'); a view of environmental damage to the Meadows focused solely upon visual impact; a belief that council has a clear mandate to progress P&R, and that objections could and should be over-ruled.

*Illustrative analysis of economic storyline*

This storyline was used both by park-and-rider Cabinet members, and by the business lobby, adopting predominantly Administrative and Economic Rationalist discourse (Dryzek, 2012). It incorporated expressed views including: “The vitality of the region depends on the P&R,” “The P&R is required for economic development,” “The P&R is an investment,” “Jobs depend on the economy,” “The P&R will demonstrate a ‘can-do’ attitude,” and “Council income depends on business rates.” This storyline has been ubiquitous in underlying UK transport policy for decades (e.g. Channon, 1989), and emphasises the pre-eminence of economic factors above others. Locally, it has been articulated in numerous council transport policies and plans over many years. For instance, the Draft Infrastructure Delivery Programme (B&NES Council, 2014) states the proposed eastern P&R would support creation of 9,000 jobs, whilst releasing city centre sites for redevelopment. B&NES’ Core Strategy, cited in P&R Background Information (B&NES Council, 2017c), suggests that the existing P&R’s are essential to the city’s “vitality and viability,” and that in their absence, business would be lost to other commercial centres. During the meeting, it was a key focus of the park-and-rider coalition, who did not, on the whole, engage meaningfully with alternative rationalities put forward by campaigners against the P&R. This approach is in line with others’ findings (Flyvbjerg, 1998): the power of business, in coalition with decision-makers, promoting economic arguments, has often proved successful in determining the course of planning decisions.

In countering this discourse, campaigners against P&R, adopting elements of Dryzek’s (2012) Democratic Pragmatist discourse, made little mention *per se* of the local economy. They did, however, tackle the economic argument on its own terms, making the point that no cost-benefit analysis had demonstrated that the economic benefit outweighed the harms, and claiming the project to be a waste of money. The accuracy of traffic models projecting its benefits was questioned. They foresaw no benefits, using extreme negative framings, as part of a Green Consciousness discourse, to describe the proposal as: “evil,” “devastatingly harmful,” “damaging, destructive”.

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Anti-park-and-ride storylines

Campaigners’ arguments against the P&R were more diverse than those in favour, partly due to the numbers speaking (32 against, versus 13 for), and partly reflecting their tactic of challenging on several fronts simultaneously, providing scrupulous evidence, from all angles, to demonstrate the inappropriateness of this P&R. They frequently used a Democratic Pragmatist discourse (Dryzek, 2012) to argue for improved engagement with stakeholders, and more interactive problem-solving and political relationships. The wide range of topics and storylines covered is striking, including recurring background themes, ranging from the council’s lack of trustworthiness, to research evidence that P&R is ineffective in tackling congestion; and including the lack of an evidence base or business case, the significant, irreversible, ecological damage to the Meadows, the visual impact, alternative suggestions to tackle congestion and air pollution, transport as a complex system requiring an iterative approach to congestion-reduction, and the council’s neglect of its duty of care to both residents and the World Heritage Site setting. The careful research that had gone into a campaign not solely framed in emotional terms, was evident, as was expert organisation.

In addition to these predominantly evidence-based discourses, emotion was sometimes apparent in campaigners’ speeches: a teenager rapped about her feelings on the loss of the Meadows and the accompanying wildlife; whilst emotion often manifested as irony, or spilled over as heckling of park-and-rider speakers. The council’s visual of the P&R in 15 years’ time, was mocked with the suggestion the site had been reclaimed by nature following an apocalypse, sequoia trees having taken over, whilst another campaigner asked ironically for a warehouse store to accompany the car park. Proposals for ecological impact mitigation were derided as a pretence of a:

“happy, clappy scheme for hedgehog housing with excited children pond-dipping for newts.”

Illustrative analysis of environmental storylines

Several environmental concerns were raised by campaigners. The most frequent was immitigable visual impact, cited by conservation organisations, local Conservative councillors, and a local celebrity architect. This is a particular concern due to the site’s Green Belt status, and position within the Cotswold Area of Outstanding Natural Beauty. This element of the argument was addressed by park-and-riders, some of whom responded that the site would be screened with appropriate planting, and sympathetic landscaping. Others countered the argument, stating the site was already spoilt by existing modern infrastructure (presumably the bypass and electricity pylons), implying that once any development has been allowed at a location, there should be carte blanche for further development. This suggestion, in fact, gave weight to the campaigners’ argument that a P&R on the Meadows would be “the thin end of the wedge” with respect to further developments in the vicinity.

Campaigners cited increased flood risk arising from development on flood plains, correctly countered by proponents who stated the sites are not within the highest Flood Risk Zones 2 or 3 (Environment Agency, 2018). However, a local architect’s concerns regarding impact on groundwater, supported by a consultants’ report (Purkiss, 2013), went unaddressed, beyond comments that tarmac was not proposed. The importance of the Meadows as a habitat, a desire to preserve them for future generations, their beauty, and preciousness (often raised in highly emotional terms, and of particular importance to the children who spoke), were barely addressed by proponents, barring a reference to nature’s adaptability in the face of change.
The opposing groups conceived of environmental harm in different ways, in line with the findings of Genus and Theobald (2016). Park-and-riders viewed the harm arising from congestion and pollution as out-weighing regrettable damage to the Meadows; whilst campaigners agreed that traffic causes harm, but disagreed about the weighting of this versus the intrinsic value of the Meadows, viewing the evidence that the P&R would be the best method of resolving the traffic harms as inadequate.

Discussion

*Where are we going with transport planning in the east of Bath?*

The discourses of the two sides were each consistent in style from the consultation on the proposal in September 2015, to the abandonment of the plan, ostensibly due to objections by Highways England to the proposed access from the Batheaston bypass, in July 2017. Park-and-riders frequently emphasised benefits to business, due process followed, and expert advice underpinning the proposal. Campaigners criticised the public engagement process, dismantled the business case, challenged the council’s poor adherence to its own policies and process, and suggested numerous alternative measures aimed at reducing city centre traffic more sustainably, attending every public meeting at which P&R was discussed. They proved adept at exploiting new and old media (for instance, arranging a televised community singalong of Joni Mitchell’s *Big Yellow Taxi* on the Meadows, and releasing a “video nasty” film of an empty Odd Down P&R facility on Hallowe’en). They were also skilled at alliance-building, joining forces with newly formed groups fighting proposed cuts to library and arts funding, leaving the council appearing leaden-footed in response. Over this period, the two sides became steadily more entrenched and angry, and the Council increasingly defensive.

There was an expectation by the business and transport lobby, and their supporters in Cabinet, that their interests would drive transport policy, as frequently happens (Mazza and Rydin, 1997), but galvanisation of the community in opposition to the P&R frustrated this objective, despite attempts to frame P&R policy as balancing environmental with economic benefits, and short and longer term timescales. A shift in rhetoric accompanied by a change in practice (Sharp and Richardson, 2001) took place when the plans were abandoned. Campaigners had successfully altered power relations, despite attempts to marginalise them. The combined forces of environmentalism, and conservation of the green setting of the World Heritage Site, proved stronger than formal power in the form of the council, in this instance.

The Conservative Cabinet’s market liberalist philosophy rendered it wary of engagement with special interest groups other than business. FOBRA were courted for their support for business’ preferred transport solution, but council was guarded in engagement with others, cautious of suggested alternative approaches to congestion reduction. This served them ill: the council struggled either to engage effectively with campaigners, both organised groups and local population, or to overpower them. Campaigners forced a reversal from the council with regard to the P&R proposal, through professionalism and skilled networking: relationship-building and tenacity, combined with incisive analysis, and excellent presentation and media-handling skills.

*Who gains and who loses, by which mechanisms of power?*

The Council and business lobby, in the form of the Chamber of Commerce, and other formal and informal, overt and behind-the-scenes, relationships, acted in coalition for the period studied, the economic storyline persisting over many years in transport policy and planning, demonstrating that this is a long-lived partnership, as is usual (Flyvbjerg, 1998). The Council
were keen to appear business-friendly, with a commitment to congestion reduction, in line with the literature (Parkhurst and Meek, 2014), repeatedly linking construction of the P&R with growth and vitality of the region, and emphasising its effectiveness in reducing congestion and pollution.

This coalition hoped for a P&R, in the belief that it would both boost the economy and reduce congestion and air pollution. They were frustrated in this objective by the diverse grouping of anti-park-and-riders, who used skills of organisation, persistence, relationship-building, media handling, and data analysis and presentation, to build a powerful coalition against the proposal, and foment public pressure on the council. Despite lacking the formal power, budget or officers of the council, or the economic power base of business, campaigners were able to overpower the establishment and force a public climb-down on this high-profile project. However, neither party can truly be said to have won here, as the problems of congestion and air pollution in the city remain unresolved, with no agreed route or timeline to their mitigation.

Is an eastern P&R desirable? And what should be done?

There is no evidence in the research literature of a clear relationship between P&R and traffic reduction in the long term. Many business-people in Bath consider the likely economic benefits of increased parking capacity desirable, whilst those who believe P&R will reduce city centre traffic are enthusiastic for different reasons. However, those who, on studying the evidence, conclude a P&R may not be an effective traffic reduction measure, those concerned with global CO₂ emissions, or with biodiversity, find it harder to justify the environmental damage resulting from the development.

A reduction in traffic is undoubtedly desirable for all Bath’s residents and visitors. Following the events described in this paper, Bath is no closer to achieving this. During the confrontation, campaigners brought expertise in data analysis, generating many alternative, sustainable suggestions for reducing traffic. They built strong networks, and the media coverage they facilitated, generated new interest in Bath’s transport issues, and enthusiasm for sustainable solutions. The council could usefully tap this new enthusiasm and knowledge, using a more participatory approach to harness it alongside the business lobby and city centre residents’ groups, cutting across entrenched discourse coalitions, and providing opportunities to highlight areas of common aspiration. This will create the possibility of a more deliberative approach (Hendriks, 2009), with potential to produce a sustainable transport policy supporting satisfactory outcomes for all stakeholders, and greater effectiveness in achieving its stated objectives. For example, a citizen’s transport panel (Goodin and Dryzek, 2006) with authority to make policy, might prove more able than more traditional structures, to tap campaigners’ enthusiasm for traffic reduction, and expert knowledge of sustainable transport.

Conclusion

Discourse analysis of the January 2017 B&NES Cabinet meeting has shown that Cabinet was joined in discourse coalition by city centre residents’ associations in proposing construction of an eastern P&R. They were supported by business lobbyists and other Conservative councillors. The main storyline propounded in favour was an economic one, reflecting arguments that have recurred in promotion of P&R in B&NES transport policy over many years, forming part of an Economic Rationalist discourse (Dryzek, 2012).
The anti-park-and-ride coalition, including conservation organisations, residents’ associations for affected communities, opposition councillors, local councillors for the affected ward, and individuals, primarily emphasised the lack of effective engagement by the council, and poor evidence base of the proposal. The main storyline used to counter the proposal, as part of a predominantly Democratic Pragmatist discourse (Dryzek, 2012), was that the council was misleading the public. This reflected the breakdown in trust that had developed between council and campaigners. The second most commonly expressed was disbelief that the P&R would resolve transport problems, and thirdly, concern with the intolerable environmental cost of the P&R. Emotional, Green Consciousness arguments were also used as a lesser facet of the discourse. Opposition to the P&R led campaigners to seek evidence around the effectiveness of P&R as a traffic and pollution reduction measure, and of its environmental cost, and to compare these with relevant measures for alternative traffic reduction measures. This, in turn, led to a growing awareness of sustainability issues, both amongst campaigners, and, through use of the media, amongst the wider public. These findings were ignored by those in favour who continued to emphasise economic arguments.

Campaigners effectively exploited alliances, using traditional and new media to bring public opinion to their cause, thus generating power despite lacking either the support of business, or formal power through council structures. Victory over the council arose through persistence, a high degree of professionalism, and good media management. However, neither side can really be said to have won, in that Bath’s congestion and air pollution problems remain unresolved, with no agreed route or timelines to their mitigation.

Implications for Future Park-and-ride Practice

Little evidence exists concerning current the general public’s opinion regarding P&R, or the degree of public awareness of P&R’s sustainability. This area provides considerable scope for further research.

The analysis of the storylines here gives insight into the arguments and methods at play in such controversial projects, and suggests that a more deliberative approach (Hendriks, 2009), bringing together business and residents in dialogue, and cutting across entrenched discourse coalitions, would provide opportunities to uncover areas of common aspiration. This could have generated a more consensual proposal, with greater likelihood of achieving its stated aims.

The study also contains suggestions for effective practice for environmental campaigners opposing infra-structure projects, illustrating the importance of organisation of the campaign, knowledge of planning processes, nimble and imaginative use of new and old media, an emphasis on the use of evidence and data alongside emotional arguments, and applying these approaches to rigorously interrogate the proposal from every angle. Whilst this is only a single case study, it is hoped that the findings may encourage more effective resident engagement by local authorities involved in similar projects.

References


Abstract: A variety of building labels and norms exist that set evermore-ambitious environmental and energy performance targets. In parallel, a growing number of building performance evaluation tools are adopting the life-cycle assessment (LCA) methodology to allow verifying if a project, based on its detailed description, reaches these targets. However, such norms and tools seem unsuited to the district scale, where environmental impact considerations are often left out of the urban planning and design process. There specifically appears to be a lack of decision-support instruments that can relate urban-scale performance targets to concrete design choices, taking into consideration the project’s specificities (e.g., climatic context), but without requesting design information that is not yet available. This paper presents the first phase of a collaborative research and development project, aiming at developing a novel decision-support method to integrate life-cycle objectives from the masterplanning stage. In this first phase, we investigate barriers and requirements from a practice-oriented perspective in the Swiss context by: (i) exploring urban-scale LCA-based methods and tools, and (ii) engaging with key stakeholders who hold complementary roles in a case study district project, which aims to be low-carbon. These exchanges are conducted in the form of a focus group and a questionnaire to gather qualitative and detailed information. Our findings notably highlight the mismatch between the ambitious objectives set by regulations and labels and the (lack of) means available to practitioners to support them in achieving these objectives. Specifications for a novel tool are derived from the practitioner’s feedback, as well as information on relevant design parameters and performance indicators.

Keywords: Life-cycle assessment, building environmental performance, urban planning and design, user requirements, environmental impact targets
The European Standards “Sustainability of construction works” series (EN 15643) and notably the building-level EN 15978 (CEN/TC 350, 2011), which details an LCA-based environmental performance calculation method, also demonstrate the relevance of this topic. Moreover, the EC published in 2014 an initiative to promote a more efficient use of resources, highlighting the importance of embodied GHG emissions of buildings and the need to consider the entire life-cycle of a building in order to effectively tackle its environmental impacts (EC, 2014).

In addition to these – not yet legally binding – instruments, some voluntary initiatives and labels have integrated LCA considerations within their framework. This is the case for example of the MINERGIE® (-A and (-A/-P)-ECO) building label, which defines a lower and upper non-renewable primary energy target for the construction (embodied) and operational phases. In the case of the -ECO label, these values differ based on the building’s usage (or program, e.g., school, housing, office) (MINERGIE, 2014). Similarly, the Swiss Society of Engineers and Architects (SIA) also defines program-specific targets for non-renewable primary energy and GHG emissions related to embodied and operational energy (SIA, 2017). However, for both of the above examples, targets refer to the individual building scale and do not depend on the project’s specificities such as its location.

Focusing on the urban district scale, the One Planet Living© (OPL©) procedure defines targets in terms of energy and GHG emissions for embodied and operational energy (Chappaz and Guisan, 2014). However, these targets are fixed and independent not only of the different building programs to be found on the site, but also of the site’s context. The DGNB’s Urban districts scheme also includes LCA criteria, but does not require individual buildings to be certified for district certification, specifying that “the assessment focuses on the areas between buildings in a district” (DGNB GmbH, 2018). Other standards or rating systems, such as BREEAM Communities (BRE, 2017), promote a life-cycle approach and attribute credits to the embodied impacts of materials, but without providing further design guidance.

Integrating environmental performance considerations through an LCA-based approach at the district scale is receiving increasing attention also in research (Lotteau et al, 2015; Mastrucci et al, 2017). Through a review of papers related to LCA at the neighbourhood scale, Lotteau et al (2015) highlighted as an issue the lack of contextualization of the LCA methods to the specificities of the neighbourhoods. They concluded on the need for approaches that remain in line with the data available at the design stages of a neighbourhood development project.

This general lack of contextual and district-scale oriented approaches – in particular for defining sublevel (e.g., building-scale) targets from overarching district-level performance objectives – is a core motivation for the current project, introduced below.

**Research context and objectives**

This work represents the first phase in a collaborative research and development project (henceforth ‘R&D project’) between academic and industrial partners, who have come together around a common district renewal project located in Switzerland (henceforth ‘district project’). The general goal of the R&D project is the development of a novel method for enabling decision-makers to integrate environmental performance considerations from the masterplanning stage. The motivation notably comes from the fact that, whereas ambitious environmental performance objectives are expected to be set for the whole district, stakeholders have little guidance or tools at hand to translate these site-level objectives into concrete and specific design choices. The lack of information moreover prevents them from
being able to judge how ambitious these targets are regarding architectural possibilities and economical constraints.

The goal of this first phase of the R&D project was thus to explore the research around LCA at the urban scale, as well as LCA in practice from the standpoint of the different stakeholders, to ultimately define user requirements for a novel urban decision-support method. The profile of the industrial partners involved in this study and who hold complementary roles in the urban planning and design process are listed in Table 1. The R&D project is led by two academic researchers (two first authors of the current publication) who are part of the same research group. It is to note that our approach is of a qualitative and in-depth nature, consisting in having regular exchanges with a small but interdisciplinary group of professionals over the one-year duration of the R&D project. As such, we do not aim for quantitative or generalizable findings.

Although the authors have attempted to objectively report the partners’ opinions in this paper, the risk of misinterpretations remains. For this reason, and given the early stage of the district project, both the exact location of the project and the identity of the partners are kept anonymous.

The remainder of the paper is structured as follows. A brief review of existing (urban) LCA tools is presented in the next section, followed by details on our approach for gathering information from the project partners. Results are presented in the outcomes section, where we also compare our observations to those of extensive LCA studies recently published.

<table>
<thead>
<tr>
<th>Industrial partners</th>
<th>Role in district renewal project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contracting authority / owner (owner)</td>
<td>Project manager</td>
</tr>
<tr>
<td>Urban designer / planner (urban planner)</td>
<td>Consultant during the elaboration of the land-use plan</td>
</tr>
<tr>
<td>Consultant specialized in CO2 emissions reduction (CO2 consultant)</td>
<td>Consultant in the elaboration of the district’s carbon emissions mitigation strategy</td>
</tr>
<tr>
<td>Engineer (engineer)</td>
<td>No role for the moment, possible involvement at a later stage</td>
</tr>
<tr>
<td>Sustainable development consultant in a major construction company (construction company)</td>
<td>No role for the moment, possible involvement at a later stage</td>
</tr>
</tbody>
</table>

Table 1. Participants profile and role. Titles within parentheses are used to refer to each participant in the remainder of the paper.

**LCA-based urban scale tools**

Conducting an LCA-based performance evaluation is particularly contextual, as it relies on regional/national databases of life-cycle environmental impact values (Kotaji et al, 2003). For this reason, we here focus mainly on methods and tools either developed for or holding the necessary data to be applicable in the Swiss built environment context.

In terms of tools, we have identified the web platform SMEO for sustainable districts (Riera Perez et al, 2014; Roulet and Liman, 2013), an Excel-based calculation aid for the development of 2000-watt society sites (Intep, 2012; Kellenberger et al, 2013), and City Energy Analyst (CEA), a collection of tools either in stand-alone open-source Python (for
researchers) or GIS plug-in (for planners) format still under development (Fonseca et al., 2016; Fonseca, 2017).

Aside from differences in the level of details regarding user-inputs, the above example tools follow the same workflow: they evaluate a project based on its description as provided by the user. This implies demanding from the user some information that is yet unknown, such as material types, or else making assumptions for instance by setting default code- or label-compliant values. Either way, the evaluation is done for one hypothetical project and iterations, for comparison between project alternatives, must be done manually by the user. This process provides low design support while being time-consuming, two of the main reasons why LCA software are not widely used by practitioners according to Jusselme et al. (2018).

Moreover, although conceived for evaluating urban-scale projects, the above tools apply building-level targets to benchmark individual buildings, of the same program, to the same performance objective. They make use of the non-renewable primary energy and GHG emission targets provided in a guiding document published by the SIA (SIA, 2017). As mentioned earlier, these targets are distinct for each building usage and domain (i.e., embodied vs operational energy). Since they are set at the individual building level, the same target will apply e.g., to two residential buildings A and B located on the same site. No contextual specificity is taken into consideration. For example, let’s assume that site constraints impose a certain shape for building B that is detrimental to its performance, while building A benefits of a larger design freedom and higher solar exposure. In that case, it might be interesting to capture these characteristics and derive contextual impact targets for each building, that still allow reaching the overarching site-level objective. The SIA itself captures this problem by observing that “[...] target values cannot be reached for each building. Some initial situations exclude or greatly complicate the achievement of the objectives.” (SIA, 2011) (translated from French). This should be addressed through a method that allows, on the one hand, verifying the feasibility of reaching specific targets given contextual considerations, and, on the other hand, adjusting the targets for each building (or other sublevels of the site) in a way that ensures the whole site can reach its objective.

While the above issues are the core motivations for the current R&D project, this paper first aims at casting light onto the user requirements as a first phase towards developing a novel approach.

**Method for identifying needs from target stakeholders**

Identifying and specifying the context of use as well as user requirements are the fundamental first steps in the process of developing a new method or tool, in a human-centred design approach (Maguire, 2001). To do so, two complimentary techniques were here used to gather information from the partners: a focus group and a follow-up online questionnaire. The reasons for using and combining these two methods are further described below.

A focus group is a qualitative data collection research method that consists in bringing together stakeholders in a discussion group format (Langford and McDonagh, 2003; Maguire, 2001; Morgan, 1996). In the field of human-centred design, it can be used for identifying requirements and issues to address (Maguire, 2001). Focus groups are often used in combination with other techniques such as in-depth individual interviews or surveys (Morgan, 1996), for which they can provide valuable insight, for instance when defining alternatives for closed-ended questions in a survey (Stewart and Shamdasani, 2015).
In the field of LCA, Saunders et al. (2013) conducted two focus groups of respectively 12 and 8 participants including architects, engineers, and contractors to investigate the reasons for the observed lack of whole-building LCA. Their findings then served in the development of a survey that was answered by 250 respondents. Similarly, Meex et al. (2018) combined a survey (364 respondents), interviews (5 participants), and a focus group (12 participants) with architects to identify design-oriented user requirements for LCA application. Focusing on how embodied GHG emissions are calculated within industry practice, De Wolf et al. (2017) conducted focus groups (48 participants) followed by semi-structured interviews (12 participants). While these examples involved a relatively large number of respondents, possibly in an attempt to derive generalizable findings, the current study does not share this aim, as mentioned earlier. However, the specific feedback gathered from the project partners, which serve to illustrate their point of view, is balanced with the broader findings extracted from the literature review.

The combination of a focus group and questionnaire is particularly useful in the context of this research. The former offers a semi-structured way of gathered qualitative information from the group of participants, exposing in real-time the converging and diverging elements. The questionnaire represents a more structured means of obtaining answers to specific questions that would not have been adapted to the focus group discussion setting. Moreover, some questions already brought up during the focus group can be repeated in order to verify if individual answers differ from the aggregated group answer. More information on how both procedures were conducted are presented below.

**Focus group**

A kick-off meeting was organized by the academic leaders to launch the R&D project. An overview of the project’s general motivation, context, and goals was first presented. The focus group discussion then took place. The entire session lasted about two hours and was audio-recorded. A list of questions developed prior to the meeting and presented in Table 2 was used as a guide during the focus group. Since exchanges with the participants began from the inception of the meeting (i.e., during the introduction presentation), the whole content of the audio-recording was subsequently transcribed and analysed. This engagement from participants also had the effect of naturally guiding the discussion, reason for which the guide was only loosely followed and additional spontaneous questions were raised by the moderators. The analysis was done by extracting from the transcript the key points and structuring them according to themes as well as partner roles. Excerpts in the form of quotes are presented in the outcomes section. To plan and subsequently analyse the focus group, and since the project does not involve a social scientist, references on the subject were consulted to extract guidelines (Langford and McDonagh, 2003; Morgan, 1996; Stewart and Shamdasani, 2015).

**Questionnaire**

As a complement to the focus group, an online questionnaire was developed and sent to the partners three weeks later. It included questions for gathering: the knowledge and satisfaction level of participants regarding specific software; their perception concerning barriers to the consideration of environmental performance objectives; the types of design parameters and performance indicators of interest (i.e., potential inputs and outputs of a tool); and general information on the phases during which they intervene over the
development of a new district. Some of these questions and their answers are presented in the next section.

Instructions sent along the questionnaire informed the partners to answer only the questions which were relevant to their professional activity. As such, the response rate for each question varies. Moreover, one participant (the owner) did not fill in the survey likely due to self-exclusion given their background and actual role in the project.

### Table 2. Sample of focus group guide, loosely followed during the discussion.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
</table>
| Today in your practice, do you encounter life-cycle performance objectives for the projects on which you work? | If so:  
  - Where do these objectives come from? Are there legal obligations?  
  - How often are such objectives present?  
 If not:  
  - How come? Because there is no requirement/demand? Because there are no tools? |
| According to you, how critical are environmental performance objectives for a project? |  |
| When working at the urban scale, which type of tools do you use?          | Are they well-suited to your needs?                                     |
| Do you know these existing tools? [referring to example tools such as those presented in the Introduction of the paper] |  |
| How do environmental performance criteria influence the design / the evolution of a project? |  |

### Outcomes from investigation

**General findings**

From the very start of the meeting with the partners, questions arose regarding the meaning of terms such as zero/low carbon and zero/low energy (buildings or in this case districts), and in particular the evaluation scope (or boundaries) for each concept (e.g., including or not energy related to materials and mobility). The definition of these terms is out of the scope of this paper and covered in multiple publications (e.g., Marszal et al, 2011; Sartori et al, 2012). While such confusion about definitions and boundaries, and their divergence, is commonly encountered and highlighted in the literature around LCA (De Wolf et al, 2017; Saunders et al, 2013), it appears clear that including the often left-out embodied energy/carbon and explicitly communicating the evaluation boundaries are essential requirements. These needs are also recurrently highlighted in the literature (Lotteau et al, 2015; Mastrucci et al, 2017; Meex et al, 2018).

This initial questioning has as a result that practitioners who approach the topic immediately face a difficulty, as expressed by the urban planner: “If someone asks us a zero-carbon district, we won’t really know how to proceed. We are rather lacking in methods. We fall back on our common methods [e.g., bioclimatic principles], which work fine, but are not necessarily up to our ambitions. I would find interesting to see how we can, throughout the masterplanning process, already get to suggestions that allow to be intrinsically more economical [in terms of energy, emissions].”

This quote also highlights a lack of means to integrate environmental performance assessment early on during the masterplanning stage, when there remains a large freedom in the design choices, among which choices that can strongly affect the performance (Kohler and Moffatt, 2003; Lechner, 2009). This lack of means was actually expressed by the CO2 consultant: “There are labels and objectives, but nothing that says how to achieve them before the end of the project’s realization phase. I see the utility of a tool at the very beginning of the project, to figure out how to design my project so that it can fulfil a given label.”
These statements also point to the limited guidance provided by existing instruments (e.g., standards, labels) and evaluation tools when it comes to supporting practitioners in their decision-making process.

Practitioners also expressed a feeling of being somewhat trapped between on one side, pressures and demands from the market, i.e., having to ensure market competitiveness, and on the other side, growing awareness and expectations surrounding sustainability-related measures and objectives. They mentioned perceiving a (lasting) conflict between the financial market and sustainability in today’s reality. As such, what came out as a crucial requirement is the need for a method that can allow verifying if a project can be high-performing (in terms of operational but also embodied energy over its lifetime), without compromising its competitiveness on the market. That is to say, professionals would like to be able to know well in advance the relationship between performance level and costs, and extract arguments from this information when communicating with other stakeholders.

**Barriers to environmental performance consideration**

The main barriers to considering environmental performance objectives, as perceived by the respondents, are presented in Figure 1. The number one barrier differs among the partners; the lack of legal obligation was identified as the prime obstacle by the urban planner and engineer (and was rated barrier number three by the CO2 consultant), whereas the CO2 consultant selected the lack of interest from the client (also the engineer’s barrier number five), and the construction company representative pointed to too high costs (barrier number four of the CO2 consultant). Lack of information / knowledge was selected by all respondents except the engineer as the second most important barrier, while the lack of decision-support tools was identified as barrier number three for the urban planner and construction company, and barrier number six for the CO2 consultant.

![Figure 1. Survey responses to the question “What barriers do you perceive to the consideration of environmental objectives?” and “Please rank these barriers in order of importance (1=most important)”](image)

All barriers in the provided list of options were selected at least twice, and two additional barriers were specified: that environmental objectives are taken into account too late in the planning process (engineer), and that their consideration disrupts the chain of decisions (construction company). We can speculate that these two aspects are partially caused by the lack of adequate methods and tools to seamlessly integrate such considerations during the planning and decisional process.

Our main results notably match those of Saunders et al (2013) and Olinzock et al (2015) who investigated, respectively through focus groups and a survey, the experience of members of the architecture, engineering, and construction community with LCA. They identified as main barriers the cost and time requirements of conducting an LCA, and the lack of demand
from clients, of government incentives, of data, and of understanding of LCA. Saunders et al (2013) highlighted the following question representing a barrier to the validation of LCA: “How do you prove sustainable options are a must to clients?”. We could relate this question to the position of our participants regarding the market competitiveness as discussed earlier, for which they need “proof” that sustainable options can be financially viable.

**Specifications**

The outcomes from the focus group and questionnaire have been consolidated into the list of user requirements presented in Table 3, which can then serve to inform the development of a novel decision-support method (this step, out of the main scope of the current paper, is briefly discussed in the conclusion section).

Table 3. Summary of user requirements (“wish list”) as extracted and interpreted from the focus group discussion and survey results. Soft requirements (less critical, “nice to have”) are italicized.

<table>
<thead>
<tr>
<th>General / Purpose</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clear methodological approach</td>
</tr>
<tr>
<td></td>
<td>Simple quantification tool, adequate for usage as early as the start of the project</td>
</tr>
<tr>
<td></td>
<td>Support dialogue between project actors in real-time (e.g., during collaborative sessions)</td>
</tr>
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<td></td>
<td><em>Dynamic tool that incorporates new technologies (e.g., in constructions) as they emerge, enabling an up-to-date and long-term follow-up of a project</em></td>
</tr>
<tr>
<td></td>
<td><em>Types of analyses and uses</em></td>
</tr>
<tr>
<td></td>
<td>Assess impact of masterplanning decisions on environmental performance</td>
</tr>
<tr>
<td></td>
<td>Quantify the sensitivity of the environmental performance to the different decision parameters (see also Figure 2)</td>
</tr>
<tr>
<td></td>
<td>Identify decisions that could compromise project’s ability to achieve goals or constrain downstream decisions (sort of risk assessment)</td>
</tr>
<tr>
<td></td>
<td>Assess impact of specific financial investments in relation to environmental performance</td>
</tr>
<tr>
<td></td>
<td><em>Quantify added-value in terms of market competitiveness related to achievement of performance labels</em></td>
</tr>
<tr>
<td></td>
<td>Propose construction mode according to project location (based on nearby resources)</td>
</tr>
<tr>
<td></td>
<td>Identify synergies at site level (e.g., between buildings)</td>
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<tr>
<td></td>
<td>Provide guidance regarding existing buildings (to protect/maintain or deconstruct/rebuild)</td>
</tr>
<tr>
<td></td>
<td>User-inputs (see also Figure 2)</td>
</tr>
<tr>
<td></td>
<td>Quantity and nature</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation</td>
<td>Scenarios</td>
</tr>
<tr>
<td></td>
<td>Facilitate the evaluation and comparison of multiple project scenarios and design options (in terms of their impact)</td>
</tr>
<tr>
<td></td>
<td>System boundaries and methods</td>
</tr>
<tr>
<td></td>
<td>Clear positioning of the method with respect to definitions (e.g., low-carbon, zero-energy), local/national legal frameworks, labels, etc., and (reliable/recognized) data sources.</td>
</tr>
<tr>
<td>Outputs</td>
<td>Target definition and benchmarking</td>
</tr>
<tr>
<td></td>
<td>Provide options for the frame of reference which sets these overall site-level performance objectives</td>
</tr>
<tr>
<td></td>
<td>Indicators</td>
</tr>
<tr>
<td></td>
<td>Visuals</td>
</tr>
</tbody>
</table>
We notably observe a need for a quantification tool that is adequate for real-time and early usage during the typically collaborative planning phases of a project. The different types of analyses that users would like to be able to conduct include assessing the sensitivity of the environmental performance to different parameters (e.g., choice of construction material), and anticipate the costs related to different scenarios by knowing the relationship between design decisions and associated construction costs.

To infer on the types of user-inputs that may be the most relevant to the potential users, the survey included a question on the types of parameters with which each partner typically works during a district project, and at what level (or scale) these are specified. For example, specifying the window-to-wall ratio at the site level would mean that the same ratio is applied to all buildings on the site. Answers to these questions, shown in Figure 2, bring us information regarding the fundamental versus secondary/too detailed parameters. The former includes the building program and the grid orientation, which could thus seamlessly be part of the user-inputs and exploited to contextually delimit the evaluation. However, parameters that were not selected by the respondents but that may still influence the different performance indicators should not be neglected. A proper method will have to be defined to reconcile the need to take such parameters into account with the fact that they are not relevant to the decision-maker at the targeted design stage. Indeed, one of the desired analysis is to be able to identify decisions that could compromise the project’s ability to reach its objectives. This implies being able to anticipate the effect of downstream design decisions.

In terms of outputs, our partners have unanimously selected costs and GHG emissions as the main indicators of interest, followed by primary energy and its non-renewable part, and a feasibility indicator. The latter would inform on the technical and architectural feasibility of reaching the performance goals, given the project’s characteristics (Figure 3).

Comparing our results with those from Meex et al (2018), who compiled a series of user requirements for LCA-based assessment tools for early stage building design, we observe a general agreement. One notable difference, aside from the targeted scale of evaluation (district vs building) and their intradisciplinary pool of architects, is their finding that architects are more interested in an aggregated single score than various environmental indicators. Within our panel of stakeholders, this choice of output received only one vote.

**Conclusion**

This paper is based on the hypothesis that life-cycle environmental performance regulations will imminently become compulsory, leading to the need for urban-scale methods and tools supporting the integration of these constraints into the urban planning and design process. To define the specifications for a novel decision-support tool, we have explored the current state of LCA-based urban-scale project assessment both from the research and practice side in the Swiss context.

Adopting a user-centred design approach, we have engaged with key stakeholders having complementary backgrounds around a common district project, chosen for its ambitious environmental targets. Current barriers as well as user requirements were identified through a focus group discussion and follow-up survey. A major barrier, highlighted both in the literature and by the interrogated partners, is the fact that practitioners perceive little pressure to integrate environmental performance criteria into their activity. This demonstrates that the objectives and ambition set at the European and national levels have yet to become legally binding and embedded into the daily practice of the practitioners.
Figure 2. Parameters selected to the questions “Which are the parameters with which you work in the context of a district project?” and “At which scale do you specify these parameters?”.

Figure 3. Survey responses to the question “What would you like to be able to get as output data (results) from a decision-support tool?”.
Environmental performance is still often reduced only to the operational energy and biodiversity aspects, which are moreover treated as non-critical and secondary issues and hence do not exert much influence on the project. Practitioners also raised shortcomings of existing targets set by norms and labels, which do not translate into solutions that exist in terms of design and construction choices.

The outcomes indicate a need for a contextual target-cascading method, i.e., a decision-support instrument that can convert a district performance objective (e.g., 2000-watt society targets) into specific sublevel targets (e.g., per building or component), while considering the site’s properties (e.g., climatic context). This method shall also allow identifying trade-offs between environmental impacts and economic indicators across distinct project scenarios involving different design choices. Building upon this study’s findings, including our analysis of the literature and of the exchanges with the stakeholders, the next step of the project will be to translate user requirements into a method towards the development of a novel decision-support tool.

Acknowledgements

This research is conducted at the Ecole polytechnique fédérale de Lausanne (EPFL) and co-financed by the NPR program of the state of Fribourg (project number PC-2017-03) and the COGENER SIG fund. We would like to thank the partners of this project for their collaboration and the rich exchanges that have made this study possible.

References


Intermediate urban regions role in improving informal areas in Egypt.  
Case study of Boulaq Ad-Dakrour

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Abstract: The informal areas are increasing significantly, especially in developing countries, affecting on economic and social life aspects in adjacent urban community that creates an inter-region area between formal and informal settlements with an urban characteristics to qualify it to be an economic center serving its surrounding areas, reducing urban poverty and absorbing the migration movement to urban centers.

The research aims to study the intermediate urban regions and their important role in improving and preserving surrounding areas in the urban areas or developing and upgrading the informal areas, which aims to find and introduce new framework for developing informal areas based on multi-dimensional aspects by activating the role of the intermediate regions for a sustainable urban progress.

We have found a way, which we believe is the first of its kind, to accurately analyse the intermediate region status in great Cairo, Egypt, setting an upgrading system as a development centre point for its surrounding within a specific legislative executable collaborative framework for the region. The paper suggests a conceptual framework for achieving an affective sustainable intermediate urban region indeed, it can help in minimizing the informal areas growth with the focusing on multi-dimensional aspects such as economic, administrative , social and urban aspects.

Keywords: Intermediate urban regions, inter-regions, adjacent area, Egyptian informal areas, Boulaq Ad-Dakrour.

Introduction

Interpretations of urban, rural and informal areas are divided into sub-categories that help to understand how community centres evolve considering the social and economic conditions of inhabitants for each region.

The adhesion of urban with informal areas has been reflected in attempts to recognize their rights at urban and non-urban levels that trying to find their widespread reasons by working on urbanization sustainability, also upgrading the existing urban network with its infrastructure.

The convergence of different urban communities has resulted an adjacent part emergence between formal and informal neighbourhood called “inter-regions” which are intermediate areas that combine urban and informal characteristics affecting on their surrounding by providing services and network. These regions are affected by degradation sprawl caused by informality as it is considered as a kind of city urban deterioration.

Many terms used to define deteriorated areas which can be classified as illegal settlements - informal communities - unsafe areas – shantytowns – heterogeneous urban texture areas - underserved areas - But otherwise, we see the term "people’s built areas" and the emergence of this term to define them as areas that self-help inhabitants to solve the housing crisis and meet their material needs without the intervention of the state without planning.

The problem is the absence of activating inter-regions role and their impact in developing urban surroundings. This is the gap that the authors want to fill, although many researchers study the interaction between rural and urban regions (Tacoli, 1998),and the role of the small and intermediate urban centres in rural and regional development.
(Satterthwaite & Tacoli, 2003) have concentrated on how to respond the needs of low income groups to increase their options and reduce pressure on urban basic services with attention to local conditions affecting with size, economic base and administrative boundaries diversity of these intermediate centres. Harody & Satterthwaite, 1986, at “Small and intermediate urban centres” focused on the potential role of small and intermediate urban centres in the development process after examining the social, economic and political forces that effect on urban systems growth at five regional case studies. Jonathan Baker, 1995, at ‘ survival and accumulation strategies at the rural-urban interface in north –west Tanzania”, has attempted to highlight aspects of rural urban interaction between the district headquarter town and surrounding villages, and 2012 at “ Migration and mobility in a rapidly changing small town in northeaster Ethiopia” concentrated to assess the degree of interdependence between the urban centre and its surrounding areas which seems that an urban based development strategy focusing on small urban settlement whereby poor populations would have some economic opportunities in long term. Cecilia Tacoli, 1998, at “Bridging the divide: Rural-urban Interactions and livelihood Strategies” focused on sectoral interactions that affect access to urban from surrounding rural areas to attempt take small urban centres as starting point for development shaped but rural urban interactions within specific regional context,

The paper defined the urban centres role in rural development as “intermediate” linkages for poverty reduction. Bolay, J. C. and Rabinovich, A., 2004, at “Intermediate cities in Latin America risk and opportunities of coherent urban development” attempted to understand interactions at different level of intermediate cities and interplay between these various aspects and their relative importance, discussing the intermediation concept and its applications in four intermediate Latin American cities to make a critical examination of the hypotheses for aiding local urban management.

These references explained the unique of the research, as it highlights the role of intermediate centres in development and how to apply in the Egyptian urban communities. The paper focus on unplanned settlements on former agricultural land build informally “Boulaq ad-dakrour”, starting by a literature review on the role of intermediate region and how it can interact to improve informal areas, then case study analysis to explore a framework. The case study was Boulaq Ad-Dakrour as it is one of the informal and demonstrative regions in great Cairo; as it is surrounded by the most liveable regions in Giza as Almohandseen and Al Dokki.

The results of the framework are encouraging and show that how intermediate regions can improve informal areas by using multi-dimensional aspects; urban, economic, social/administrative to guide the development of informal areas and decision making needed.
Definition of inter-regions:

Intermediate regions may consider as an effective tool for integrating formal and informal economies and achieving a balance population distribution in urban centres to reduce pressure on infrastructure, services and resources in cities, providing support functions to improve and commercialize the informal local economy, enhancing income and purchase power to improve daily life quality (Tacoli, 1998).

We can define the "inter-regions" which are communities separated from urban, rural and informal areas, and may be divided into intermediate urban areas which are separable between urban and peri-urban areas, and rural inter-communal communities, separating rural and peri-rural areas.

Inter-regions emerge as result of inter-linkage between existing urban centres institutions and informal area users that greatly depends on these regions role as an economic growth catalyst through local markets and services for many urban and non-urban dwellers (Satterthwaite & Tacoli, 2003).

These areas can be defined as heterogeneous multi-core regions (Ascher 1995), that help to develop their surrounding informal areas from economic, social and urban aspects, and integrate with urban and rural centres as shown in Figure 2.

Figure 2: Diagram of Interlinking between urban, rural and informal areas
Source: Researchers
Basis of classification of inter-regions:

To explain this classification, it has been shown that it is important to know how cities consider the main aspects direction of "mediation and intermediation", eight basic dimensions were identified (Bolay, 2002):
- Demographic: Based on urban growth and the impact of migration movements.
- Economic: Based on productive and commercial sectors feeding local markets and services.
- Political and institutional: based on the analysis of public institutions serving the local population, in line with their nature, function and regional scope.
- Specialized services and equipment providing services to residents within or outside region.
- Environmental: through the identification of resources that facilitate life while reducing pollution extent resulting from urban activities.
- Land management: The primary focus is on planning, regulating the environment and its consequences on human settlements.
- Social: Reflecting behavioural changes and mixing within the family and social networks.
- Cultural: through emergence of new forms of total expression of local cultures and external influences resulting from the exchange between urban and external areas.

Intermediate urban regions role for developing informal areas:

Inter-regions location helps to understand informal area needs and exploit the urban centre potential to achieve the most benefit possible (Satterthwaite & Tacoli, 2003). The spatial objectives of urban policies assume that intermediate region play an important role in informal area development through four main points:
- Providing marketing centres for products in informal areas.
- Providing essential services required to inhabitants.
- Promoting local industrial activities.
- Attracting internal migration and reducing overcrowding in major urban centres.

These roles lead to maximizing intermediate region use of surrounding these urban centres, whether upgrading informal area to maintain the identity and level of urban areas through two factors: a tangible factor of services, as well as an intangible factor of social and cultural development. Thus helping to reduce poverty both in urban and non-urban areas.

Hence, local government's role in inter-urban areas development should take action in ensuring urban centre services existence to its neighbouring regions.

Inter-regions can be exploited as important development points urban and architectural benefit wise, the proximity of the inter-regions with urban centres may help to transfer and renovate architectural and urban character of informal sector affected from its neighboring urban regions to be a turning stimulation point in the entire surrounding informal urban planning of the city (UN-Habitat, 2015).

Case study: Inter-region of Boulaq Ad-dakrour:

The target area locates in Giza governorate in the western side of Nile river, with population 140,670 inhabitants, surrounded by El-Dokki and El-Mohandessin area at the east that represent the urban aspect, and Imbaba and Ard El-Iewa at the north, Saft El-Elban & Kafr Tuhurmis at west representing the neighbouring informal areas. The district is divided into seven Sheyakhas (administrative subdivisions): Boulaq Ad-dakrour – Zenein – Manshiet Elian – Kafr Tuhurmis – Abu Qatada – Nazlet Bahgat & Nazlet Khalaf. In the past, it
was an agricultural area before transforming into informal buildings area in a short time, and then it becomes an attractive area for low income immigrants from Upper Egypt.

Boulaq Ad-dakrour has strong economic interlinks with their surrounding urban areas: El-Agouza, El-Dokki & El-Mohandessin that lead to high rate of migration for relative cheap housing prices.

This area separates by several obstacles from its neighbouring areas, as shown in figure 3, including the railway, Metro line and El- Zomor Canal, while existing of many entrances across the area from ring road at the west, July axis at the north and number of pedestrian bridges from the east.

**Figure 3: Boulaq Ad- dakrour map**

*Source: Researchers*

**Characteristics of Boulaq Ad-dakrour area : (selection reasons)**

The authors choose Boulaq AD dakrour as a case study for many reasons as it is:

**Socio-economic characteristics:**
- Strong social relations among residents which represent a social safety network.
- Easy access and small distances to surrounding urban centres.
- NGOs in Boulaq Ad-dakrour focus mainly on helping women and poor families in food, monthly salaries or some medical services.
- Limited job opportunities in the area with weak skills for graduates which leads to seek outside urban centre for opportunities or turn to low income and several problems.

**Administrative characteristics:**
- Need more governmental service branches and departments from local administration where there is no police stations or services to regulate markets and vendors which led to traffic obstruction and garbage spreading.
- Lack of roles and responsibilities distribution between local administration, NGOs and private sector for upgrading Boulaq.

**Urban characteristics:**
- Services and rent prices are relatively lower in Boulaq than its surrounding urban centres which makes this area attractive to several groups especially workers and migrant from Upper-Egypt.
Figure 4: Boulaq Ad- dakour analysis
Source: Researchers
- Provided infrastructure services quality to be inferior to other surrounding districts, furthermore, sewage system is the most important problem facing people in Boulaq Ad-dakrour. Caused by local district authority that backfilled Al-Zomor Canal, this area converts into vehicle parking without benefit from it.
- Solid waste management as a main problem with impact on health and finances as well as negative effect on traffic flow and people’s daily activities.
- The most common spot for waste disposal is by Al-Zomor Canal, leading to waste accumulation and the blockage of the canal.
- Narrow streets that characterize Boulaq roads networks limit vehicular accessibility.
- Vendors’ encroachment on both sides of street hindering traffic and pedestrian movement. The situation is worsened by poorly paved roads due to continuous server overflows.
- Education quality is more deteriorated in Boulaq Ad-dakrour than outside of the area, thus many families decide to enroll their children in schools outside the area to Dokki and El-Mohandessin. There is also lack of vocational schools inside Boulaq.
- Healthcare services in Boulaq Ad-dakrour is very poor and inadequate with lack of basic medicine and public health service, also lack of services provided for special needs or elderly groups who have to seek the services outside Boulaq Ad-dakrour.
- Many private clinics and healthcare centres affiliated with NGOs or religious institutions provide healthcare services in the region that are too expensive for low income inhabitants. Recreational service – Lack of recreational facilities except the private amusement park by Al-Zomor canal and youth centres with no public library in the project area.
- Poor transportation networks linking Boulaq Ad-dakrour with neighbouring areas.
- Pedestrian bridges are crowded and very difficult to climb limiting the movement of elderly and disabled people.
- Market at El-Zomor canal where street encroachments block pedestrian and vehicular traffic, while vendors complain about the deteriorated quality of vending stalls

**Development proposal for Boulaq Ad-dakrour as a paradigm:**

The proposed interventions are based on specific problems and priorities according to their importance and geographical location as well as the impact range to surrounding deteriorated area taking into account the national strategic plans for Boulaq Ad-dakrour development, which are prepared by various departments at all levels. These interventions are easy to implement in a short period to benefit large number of inhabitants.

**Socio-economic interventions:**

A series of interventions can be divided into several points based on:
- Establish vocational and technical skills training centres by NGOs in coordination with local administration as a professional support and adopt training programs especially for young people to create sustainable employment opportunities.
- Integrate youth participation for planning and implementing sustainable projects.
- Reduce spreading of social diseases by NGOs of Boulaq region.

**Administrative interventions:**

- Increase security presence in Boulaq Ad-dakrour.
- Provide NGOs representative sample to participate in community planning.
- Provide governmental departments.
- Determine roles and responsibilities between governmental local administration, NGOs, private sector and Boulaq inhabitants at all development processes.

**Urban interventions:**

Projects that work on urban development in Boulaq Ad-dakrour can be divided into several levels according to problems posed in the previous section.

- First for infrastructure problems especially in sanitation, this type of projects requires state institutions to develop and modernize networks.
- Using main streets surround borders as a key connector between the study region and neighbouring urban areas where will contribute to increase pedestrians density and vehicles resulting streets movement improvement and enhancing sense of security.
- Renovate available healthcare service units in collaboration with NGOs and provide specialized healthcare units.
- Upgrade existing school infrastructure.

[Diagram of urban interventions]

- Develop urban spaces and public areas.
- Redesign border wall to be used in activities to provide employment opportunities and enter the informal sector to legal economic sector system as organizing vending activities spot on streets that need people’s need along the pedestrian and vehicular paths without obstructing people’s mobility.

**Figure 5:** Upgrading Boulaq Ad-dakrour inter-region part with Dokki district

Source: Researchers
- Set conditions for paving streets and sewage networks and work on them.
- Develop and landscape main public space in Boulaq.
- License street vendors according to space specified for them in urban design project to ensure health and safety.
- Move the market and redesign it in light of a clear understanding of real market needs.
- Organize transportation station after understanding capacity and working demands.

We can see these development steps on Figure 5, that explains how can redesign public urban space to meet people’s need at inter-region between two different communities to rely positively urban services with informal areas.

And Table 1 presents a SWOT analysis of Boulaq Ad-dakrour paradigm project:

<table>
<thead>
<tr>
<th>Socio-economic aspects</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Strong relations between the inhabitants. - Presence NGOs development role.</td>
<td>- High rates of unemployment and social diseases.</td>
<td>- Establishing vocational training centres and developing youth skills.</td>
<td></td>
</tr>
<tr>
<td>Administrave aspects</td>
<td>- Lack of governmental services. - Weakness of role distribution between authorities.</td>
<td>- Provide NGOs and governmental departments. - Determine roles and responsibilities at all development processes.</td>
<td></td>
<td>The interference between different governmental institutions may affect the development negatively</td>
</tr>
<tr>
<td>Urban aspects</td>
<td>- Relative prices of real estate and rents. - Availability of natural gas and electricity services. - A distinguished location beside urban areas services</td>
<td>- Weak level of infrastructure, especially in sanitation. - Deterioration of buildings. - Lack of adequate government services. - Weak educational and healthcare services, leading to seek outside of the region for these services.</td>
<td>- Renovating healthcare units and education services infrastructure - Redesign the market to accommodate street vendors - Upgrade public spaces and street networks.</td>
<td>- Rising land prices by upgrading levels lead to indigenous people migration.</td>
</tr>
</tbody>
</table>
**Conceptual Framework:**

This paper aims to make a conceptual framework to guide the informal areas upgrading and decision making, this framework passes many steps starting with the literature review that display the main definitions for intermediate areas, their role and importance. Then step two: case study classifications and analysis based on multidimensional aspects (Urban, social, economic, administrative aspects) and ending by SWOT analysis to form a conceptual framework that highlights the importance of this intermediate regions in urban development and upgrading, as shown in Figure 6.

**Economic Approach**
- Supporting economic activities to reduce unemployment rate in degraded areas.
- Supporting local crafts while working on a variety of activities to achieve economic integration.
- Developing existing markets in inter-regions.
- Integrating the informal economy into the formal system.

**Urban Approach**
- Availability of infrastructure services and facilities whether educational, healthcare or environmental services.
- Organizing public spaces used by inhabitants to improve their efficiency.
- Land use regulate according to needs.
- Road networks quality for cars and pedestrians to serve communication between urban center and degraded areas.

**Social Approach**
- Availability of rehabilitation institutions and NGOs in the inter-regions to provide services to inhabitants.
- Participating inhabitants in planning and implementation stages of development.
- Convergence between the social strata of inhabitants.

**Administrative Approach**
- Organizing roles between local administrations with identification of its urban status to give an opportunity to take decisions.
- Maintaining outlets for various government services, police stations, and multiple district departments.

![Figure 6: Conceptual framework for intermediate regions development](source: Researchers)

**Conclusion:**

Unlike most related research on Intermediate urban regions, this study analyses a special case in Egypt (Boulaq Ad-Dakrour), The article highlights the important role of intermediate urban region in upgrading the surrounding areas.

From an academic point of view, this work has attempted to give a better understanding of the nature of Intermediate urban regions by studying the impact of the inter-zones in the Egyptian urban on the neighbouring areas, with delivering of urban services to the surrounding areas and preserving the urban sustainability of mutual benefit between the parties. May need some of the existing centres for development by establishing special programs to transform the area efficiency of the services and the urban network to benefit and satisfy the residence and meet their needs, while reducing the pressure of demand on the urban by strengthening the links between the characteristics of the characteristics of neighbouring regions without some negative impact on the population.
On the urban level in the road network and infrastructure or at the economic level to give the required investments, or the social level to keep up and upgrade the existing classes of population in the region, or at the cultural, recreational and environmental levels.

Inter-regions can be defined as intermediate points connect two communities with many interlinks that help create contribution centres for development of urban’s surrounding areas for facilitating services and providing their needs by delivering urban concessions to adjacent informal areas. These regions may vary in size or importance from street between two districts to large area separated different sectors according to urban classification among countries by population or socio economic and administrative level. Figure 6 shows the conceptual framework how to improve and upgrade the informal areas using an effective intermediate using these multi-dimensional aspects.

Future research should be carried out to study more Intermediate urban regions in the Egyptian context and how we can upgrade the surrounding areas by analysing the four affective approaches; it also can study the role of the intermediate urban centres in regional and rural sustainable development and poverty reduction.

References


UN-Habitat, COMMUNIQUE “THE ROLE OF INTERMEDIATE CITIES IN STRENGTHENING URBAN-RURAL LINKAGES TOWARDS THE NEW URBAN AGENDA” - 27-28 October 2015, Montería, Colombia.
The Impact of modifications to residential morphologies on the outdoor microclimate in hot dry climate cities

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Abstract: In 1991, the Iraqi Kurds established an autonomous state of Iraqi Kurdistan and has flourished in stark contrast to the remainder of Iraqi and Syria. The capital of Kurdistan is the historic city of Erbil; the city has expanded dramatically since 1991, in a series of concentric rings around the central Citadel, to accommodate Iraqi Kurds from both Iraqi and the returning diaspora. The rapid urban expansion has moved away from using the principles of design in a hot dry climate, the traditional organic designs of narrow, winding streets. This organic morphology has been superseded by a grid iron planning grid, with street widths designed to accommodate motor vehicles. The alignment of these grid iron street patterns has been driven by geometry rather than referencing urban micro climatic needs and has increased energy demands. Recent developments in urban climatic modelling have enabled researchers to investigate the impact of urban morphology on the urban micro climate. ENVI-met, a holistic three dimensional hydrostatic model has been used by researchers to investigate urban micro climates. This paper uses ENVI-met to predict climatic variables in the modern grid iron urban pattern of Erbil, focusing on the prediction of Dry Bulb Temperature, Mean Radiant Temperature and wind speed. These predictions were compared to weather stations located in the urban development of Erbil, in common with other researchers, good agreement was achieved during the day light hours, less so during the night time. Using ENVI-met the orientation and street canyon widths have been investigated to achieve the highest wind speeds around buildings. These higher wind speeds can be utilised to increase natural ventilation of buildings, this will decrease the need of mechanical cooling leading to a reduction in energy consumption and will lead to more energy efficient designs.

With low rain fall and very limited water service provision, a blue/green environmental strategy was not possible. And due to limited possibilities to manipulate the urban street canyons to provide shade, meant that the possibilities of reducing the Dry Bulb Temperature and the Mean Radiant Temperature were restricted. To reduce the Mean Radiant Temperature the use of external mesh shading was explored. This reduces the sky view factor and therefore limits solar gain. The ENVI-met climatic model demonstrated significant reduction in the Mean Radiant Temperature.

Keywords: Urban Microclimate, ENVI-met validation, Modification urban morphology, Shading meshes, Mean Radiant Temperature.

Introduction

In 1991, the Iraqi Kurds established an autonomous state of Iraqi Kurdistan and it has flourished in stark contrast to the remainder of Iraqi and Syria Figure 1. The capital of Kurdistan is the historic city of Erbil, centred on the citadel, a 32 metre high walled mound, covering 10 hectares (Abdulkareem, 2012). At first sight the citadel appears to be located on high ground surrounded by a relatively flat plain. This is an illusion; the citadel’s height has been gained through layer upon layer of construction stretching back some 7,000 years (Akram et al, 2015). Within the citadel and the districts to the South, located adjacent to the main entrance, an organic urban street pattern exists, dictated by climate, availability of construction materials and transport needs (Al-Hashimi & Bandyopadhyay, 2015). With
economic and political stability, Erbil has expanded dramatically, with an urban development plan that consists of a series on concentric ring roads, with the citadel at their centre (Alkmuhtar, 2016). Urban planning of the areas formed by these concentric ring roads has taken the form a grid iron street pattern, with road widths suitable for modern cars. The orientation of these grid iron street patterns does not account for the designing of dwellings’ in a hot dry climate. Whilst the urban areas have expanded rapidly since 1991, the same cannot be said for the amenity infrastructure Figure 2. This has resulted in dwellings being poorly sited to minimise the impact of a hostile micro climate and the electrical energy needed to make them habitable unavailable at the peak time of demand, the hot summer period (Ayoob Khaleel & Ibrahim, 2010).

Recent developments in urban climatic modelling have enabled researchers to investigate the impact of urban morphology on the urban micro climate. ENVI-met, a holistic three dimensional hydrostatic model has been used by researchers to investigate urban micro climates (Chow & Brazel, 2012). This paper uses ENVI-met to predict the urban micro climate of these grid-iron street patterns and how these can be orientated and manipulated to lessen the impact of the hot dry climate on individual dwelling. ENVI-met is very much a research tool and care must be exercised in its use, so the first part of this paper is devoted to assessing the accuracy of the micro climatic predictions. This is done by modelling a portion of modern Erbil, that surrounded a weather station and then comparing the predicted air temperatures at the weather to those measured at the weather station.

Having gained confidence that ENVI-met can be used successfully to predict urban micro climatic variables, the orientation and street canyon widths have been investigated to achieve the highest wind speeds around buildings. These higher wind speeds can be utilised to increase natural ventilation of buildings, this will decrease the need of mechanical cooling leading to a reduction in energy consumption and will lead to more energy efficient designs (Radhi et al, 2013). However, the wind speeds in these urban canyons will always be low, due to the surface roughness of the urban environment and lack of climatic drivers to increase the wind speed in the region (Andreou, 2013). To reduce solar gain, the use of shading devices was explored, and these had the potential to reduce the Mean Radiant Temperature within the urban canyon.
ENVI-met

ENVI-met is a three dimensional program that simulates and analyses the microclimate urban environment. The typical resolution of ENVI-met microclimate model is 0.5 to 10 meters (Huttner et al, 2008). It uses fluid dynamic fundamental laws to calculate the dynamic of microclimate during the day and night for urban areas (Huttner, 2012). ENVI-met can accurately simulate the physics of atmospheric boundary layer of any urban area around the world (Bruse, 2004a). Simulation is normally between 24 - 48h, with 10s as maximum time step. The model also can present the energy balance for all types of urban surfaces; buildings and plants. ENVI-met can simulate the interactions between urban elements, such as weather, soil, plant and buildings in the urban scale (Bruse, 2004b). Every single structure or buildings, vegetation and soil layers can be simulated. ENVI-met contains the following sub-models (Huttner, 2012):

1 D boundary model represent the boundary conditions between 0 to high 2500m.
3 D atmospheric model. Represent building structure, plants.
3D/1D soil model represent soil temperature and moisture content in different layers.

Validation

To assess the accuracy of the ENVI-met predictions, weather data was obtained from a weather station located within an urban area of Erbil, shown in Figure 4, with the position of the weather station indicated by the red dot. The weather station had originally been sited outside the city, but the city’s rapid expansion had engulfed the weather station, making it ideal for this validation exercise. Figure 3 shows the ENVI-met 4.1.0 model of this urban area and Table 1, the initial input variables used in the model.

Table 1: The initial input variables used in the validation model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial air temperature</td>
<td>C°</td>
<td>36.33</td>
</tr>
<tr>
<td>Wind speed in 10m height</td>
<td>M/S</td>
<td>0.5</td>
</tr>
<tr>
<td>Wind direction</td>
<td>0 from the north and 180 from south</td>
<td>225°</td>
</tr>
<tr>
<td>Relative humidity in 2m height</td>
<td>%</td>
<td>14.5</td>
</tr>
<tr>
<td>Specific humidity at model top</td>
<td>2000m g/kg</td>
<td>5</td>
</tr>
<tr>
<td>Maximum air temperature at 15:00</td>
<td>C°</td>
<td>41.87</td>
</tr>
<tr>
<td>Minimum air temperature at 05:00</td>
<td>C°</td>
<td>27.66</td>
</tr>
<tr>
<td>Soil temperature in depth of 00 to 5 cm</td>
<td>(K)</td>
<td>311.23</td>
</tr>
<tr>
<td>20 to 50 cm</td>
<td></td>
<td>306.07</td>
</tr>
<tr>
<td>50 to 200 cm</td>
<td></td>
<td>300.77</td>
</tr>
<tr>
<td>Below 200 cm</td>
<td></td>
<td>298.81</td>
</tr>
</tbody>
</table>
The performance of the ENVI-met model was assessed in two ways:

1. Comparison between measured Air temperature, the observed value, and modelled Air temperature, the predicted value, at a 2m height, Figure 5.

2. Using root mean square error (RMSE) and the index of agreement (d); Equation 1. This method used is described in full by (Willmott, 1982).

Equation 1. Index of agreement “d” between modelled and predicted data

\[
\text{Index of Agreement } d = 1 - \left[ \frac{1}{n} \sum_{i=1}^{n} (p_i - o_i)^2 / \sum_{i=1}^{n} (o_i - \bar{o})^2 \right]^{1/2}
\]

The index of agreement (d) is a standardised measure of the model prediction error, a value of “1” indicates a perfect agreement while a value of “0” would express no agreement. A “good” model could be defined as one were the systematic error approaches zero and the unsystematic error approaches the Root Mean Square Error (Kong et al, 2016). Willmott proposed that the systematic error could be described by

\[
\text{Mean Square Error systematic } = N^{-1} \sum_{i=1}^{n} (P^s i - Oi)^2
\]

And the unsystematic error by

\[
\text{Mean Square Error unSystematic } = N^{-1} \sum_{i=1}^{n} (Pi - P^s i)^2
\]

By taking the Square root of both MSEs and MSEu these differences can be redacted to the units of temperature.
Figure 5 shows the air temperature plots from both the Central Weather Station, the observed value and the ENVI-met, the predicted value, from 8:00 to 01:00. The predicted maximum and minimum are below and above the respective measured values and this is in line with other researchers that have found that ENVI-met model underestimations the minimum and maximum temperatures (Chow, 2012). ENVI-met appears not to predict the night time air temperatures very well, so two data sets were analysed, the full 24 hour and a data set encompassing the day time period of 7:00 to 18:00, sun rise to sun set. The ENVI-met (P) modelled data showed generally "good agreement" compare to observed data from the Central Weather Station (O), (r² = 0.75) for 24 hours and (r²= 0.92) for day time (07:00 to 18:00). In addition, the index of agreement is (d= 0.85) and (d= 0.99) for both 24 and day time period is respectful.

The root mean square error systematic error (RMSEs) and unsystematic (RMSEu), a lower magnitude for the former is desired, Table 2 gives the comparison for the two data sets, and it is clear the ENVI-met produces satisfactory results for the day time period as opposed to the full 24 hour period.

Table 2: ENVI-met results for day time period and full 24h

<table>
<thead>
<tr>
<th>Assessment Period</th>
<th>Index</th>
<th>24 hours</th>
<th>Day time (07:00 to 18:00)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation coefficient</td>
<td>r²</td>
<td>0.757</td>
<td>0.92</td>
</tr>
<tr>
<td>Mean Bias Error</td>
<td>MBE</td>
<td>1.020</td>
<td>2.30</td>
</tr>
<tr>
<td>Mean Average Error</td>
<td>MAE</td>
<td>2.62</td>
<td>2.41</td>
</tr>
<tr>
<td>Systematic Root Mean Square Error</td>
<td>RMSEs</td>
<td>4.04</td>
<td>3.79</td>
</tr>
<tr>
<td>Unsystematic Root Mean Square Error</td>
<td>RMSEu</td>
<td>2.107</td>
<td>0.33</td>
</tr>
<tr>
<td>Index of Agreement</td>
<td>d</td>
<td>0.85</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Table 2 Analysis of errors from Measured and Observed Air Temperatures

Having gained confidence in using ENVI-met to predict day time climate conditions satisfactorily, the next step of the research was to analyse a proposed urban area of Erbil and to explore ways in which the urban form can be manipulated to increase wind speeds and reduce air temperature.

Results

1. Microclimate for Real Case Study.

Figure 6 shows the urban layout and the three stars show the positions were the canyon wind speeds were extracted from ENVI-met, before, in the centre and after an open space at a height of 2 metres from the ground.

Figure 6, An urban grid with the canyons’ aligned North – South and East - West, the grey blocks are built forms and the green blocks open areas, red starts show where data was extracted from ENVI-met.

Three wind directions were chosen, from the South, from the West and from the South West, winds from the South and West are aligned with the canyon layout. Figure 7, 8. and 7 show the canyon wind speeds for the respective wind directions.

In Figure 7, the wind direction is at right angles to the canyon, and low canyon wind speeds occur either side of the open space, the open space is aligned with the wind direction and has a higher wind speed. In Figure 8 the wind direction is parallel to the canyon, higher wind speeds occur either side of the open space, whilst the open space has a lower wind speed.
The reduction in wind speed in the open space is caused by the greater flow area offered by the space. Figure 9 shows that when the wind direction is not aligned to the urban canyon grid, lower wind speeds are predicted along the orthogonal canyons but more even flow is recorded along the canyons. The simulation results compared quantitatively and qualitatively with measured data and previous studies (Kong, Sun et al. 2016) and (Chow, Pope et al. 2011, Van Esch, Looman et al. 2012, Ruksana 2014). However, the difference predicted here are small, a slight increase in wind speed is achieved when the street canyon is aligned with the wind direction and more even wind speeds are achieved if the wind direction is at 45° to the canyon alignments.

2. Microclimate for a Proposed Design Scenario

Three interventions were made in urban fabric depicted in Figure 6, the first was to add more open spaces, secondly to increase the East West canyon widths with the extra open spaces and thirdly inset open spaces within urban blocks with the extra green spaces; Figure 10 shows these configurations, were image a shows the original urban grid, b the addition of two green spaces, c the widening of the East West canyons and d open spaces inserted into the urban blocks.

Figure 11 shows the predicted wind speeds at the three locations given in Figure 6 (before, middle and after open space), and Figure 13 shows the air temperatures at these locations for the four urban configurations, a, b, c and d. In terms of wind speeds only when...
open spaces are inserted in the urban blocks is there a change in the predicted wind speeds Figure 12. As for air temperature, there is very little variation between the four urban forms Figure 13.

Figure 11: Predicted wind speeds for all configurations, original urban grid, addition of two green spaces, widening of the East West canyons and open spaces inserted into the urban blocks.

Figure 12: Predicted wind speeds for all configurations for all interventions using ENVI-met
3. **Strategies’ to reduce air and mean radiant temperature.**

Erbil is located in a hot dry climate, and in such a climate the most effective way of reducing air temperature would by via evaporative cooling either by have open water, with or without fountains or planting, a blue green strategy (Husami, 2007). However, the availability of water is limited, low rain fall occurs in the region and this is coupled with a lack of water collection and distribution to the ever expanding urban fabric of Erbil (Rasul et al, 2016). The only other cooling strategy available would be to provide shading, whilst this will not affect the air temperature it will impact on the mean radiant temperature and result in the urban environment receiving less solar energy (Elnabawi et al, 2015). Shading could be provided by natural means, via the planting of trees but would require time to mature, to have an instant impact the researchers propose using a shading mesh suspended above the building fabric. shading mesh are used in residential and industrial buildings, such as car parks, playgrounds and swimming pools (Abdel-Ghany & Al-Helal, 2011). To investigate the impact of a shading mesh, an open space in the urban area was used. The mesh had a transparency of 50%, this would allow sufficient daylight to pass through whilst intercepting a significant portion of the solar energy and the mesh was suspended 8 metres above ground level, this

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**Figure 13**: predicted Air Temperatures for all scenarios a, b, c and d.
would allow sufficient space of wind flow through the urban space. For the purposes of this study the open space was divided into two with one half shaded and the other remained open, ENVI-met was used to calculate the mean radiant temperature and wind speed in the centre of the two halves Figure 15.

Figure 14 shows the impact the shading mesh has on the mean radiant temperature and Figure 16 show how the wind speed is affected.

Figure 14: Mean Radiant Temperature for the open space with and without shading mesh

Figure 14 shows that the shading mesh does reduce the mean radiant temperature during the day Figure 18, and not surprising, has no impact once the sun has set Figure 14. Figure 15 shows that with the mesh at 8 metres above ground level, there is only a small reduction in wind speed and ENVI-met results shown in Figure 16 and 17.
Conclusions

ENVI-met has successfully been used to model the urban climate of Erbil, the capital city of Kurdistan. Good agreement was achieved when modelling the day time temperatures', whilst night time agreement was less so. ENVI-met was then used to model the day time climate of a new proposed urban area of Erbil, by orientating the grid iron pattern so that the direction of the prevailing wind strikes the grid at an angle of 45° proved to yield the highest wind speeds in the urban grid as a whole. If the prevailing wind is parallel to either grid direction, the wind speed in the streets perpendicular to the prevailing wind direction are low as the wind is channelled down the streets parallel to the prevailing wind direction.

Because of the geographical position of Erbil and the urban surface roughness the wind speeds in the urban areas are low, various interventions were modelled to increase wind speeds but had very little impact. The most promising was a significant increase in the open spaces around the urban blocks, however it was not possible to increase wind speeds just to reduce the impact the urban form has on the wind speed.

Without evaporative cooling it is difficult to reduce air temperatures in the urban areas, but by providing shading, the mean radiant temperature could be reduced during day light hours without impacting on wind speeds.
References


Exploring sustainability in providing low-cost housing in Khartoum- Sudan

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Abstract: The Sudanese housing policies encompass two main types of programs. The first one addresses the needs of all sectors of the population for the provision of plots through site and services schemes. The second type provides small built core units (Incremental housing) for the low-income groups. The aim of the paper is to examine the evolution of sustainable design of the core units built by the public sector for low-income families. The research selected some low-cost housing projects provided in different periods of time e.g. Duim project _1949, El shabiya project_1963, Al Iskan Project _1975 and state fund projects_2001 as case studied. The analysis focused on four parameters: the size of the project, the target group of inhabitants, the design of the core unit and the construction including building materials and technologies, these parameters are compared to U.N. Habitat principles of sustainable housing. The research found that old projects had comprehensive approach including socio-economic surveys of the intended inhabitants, while new projects put more emphasis on quantities of built units than on quality of housing. Former projects used cheap traditional building materials and technologies which is more sustainable than the expensive imported materials used in new projects. The research identified the introduction of mixed housing of different income levels in new projects that guaranteed social sustainability.

Keywords: low-cost housing projects, sustainability, core-unit, building materials and technologies

Introduction

Sustainable Development is a comprehensive process of providing development within the umbrella of the four pillars of sustainability (UNDP 2002): cultural vibrancy, economic prosperity, environmental responsibility and social justice. Social sustainability occurs when the formal and informal systems and structures that support the capacity of current and future generations are linked to create healthy and liveable communities (Hodgson, 2003). In practicing sustainable community development, proposed actions and policies must be judged for their economic value as well as for their ecological and evolutionary affects, moreover following a model of sustainability requires integrating different human values with the multiple dynamics of natural systems (Flint, 2013). One of the main factors of achieving sustainability in a community is the sufficient range, diversity and affordability of housing within a balanced housing market (Egan 2014). Housing projects must be properly integrated into the social, cultural and economic local environments, it is important to connect housing to infrastructure networks and basic services (water supply, electricity, etc.).

UN-Habitat (2012) prepared a policy framework for developing countries to guide provision of sustainable housing, in which cultural and economic impacts of housing contribute to make healthy residential neighbourhoods. To achieve economic sustainability housing policies, design and construction processes should be connected to micro and macro-economic development, and employment and economic generation. Also, production of housing projects contributes to economic prosperity of the community, as stated by Davis (2015) construction of housing creates new opportunities for urban investments at the local level, it privileges the role of private developers and the housing industry and transfers responsibility for housing to smaller municipalities. Social sustainability is a serious issue in housing as it concerns with social equity in providing basic and social services and access to work. Another important factor in providing sustainable housing is the social mix of the
inhabitant of different income-levels and different ethnic groups and distributing 20-50% of the residential floor to low-income families (UN Habitat 2014).

The UN-Habitat clearly stated that it is a priority for all governments to provide adequate and affordable housing taking into consideration residents lifestyle and livelihood strategies. Provision of adequate housing requires number of conditions such as: affordability, habitability, accessibility, location, availability of services, materials, facilities and infrastructures, cultural adequacy and security of tenure (UN 2014). Availability of different types of housing tenure such as freehold, leaseholds, condominiums, cooperatives, shared leaseholds and various forms of rental housing to suit various needs and preferences of different inhabitants provides security of tenure (UN Habitat 2015).

Provision of sustainable housing involves a complex network of components: stakeholders and matters as shown in Figure (1). Each component plays an important role that affects roles of other components e.g. government policies guide urban plans, land-use and other regulations related to housing. Scaling up sustainable housing is a crucial issue in developing countries, which require supportive institutional and regulatory environment, monitoring and evaluating mechanism and appropriate capacity development of the housing sector (UN Habitat 2012). The demand for new housing projects in developing countries is huge e.g. in Nigeria, the rate of provision of new housing stock has lagged severely behind the rate of population growth resulting in staggering housing deficit (Olotuah,2010).

There are multiple alternatives of sustainable building materials such as, earth which is widely available, affordable and recyclable. It is well suited for passive solar heating and cooling, and offers a wide range of environmental benefits, including significant reductions in pollution and greenhouse gas emissions (Bayizitlioglu,2017), one example of a developed sustainable technology of earth is compressed and stabilized earth block (CSEB) which used as low-cost structural systems (Kumar et al,2018). Also, wood as a sustainable building material is durable and its greatest attribute is that it is a renewable resource, it has low carbon impact and low...
embodied energy. (Falk,2009) one example of a developed sustainable technology of organic based construction materials is straw based material that used for walls (Goodhew,2012).

**Housing in Sudan**

Sudan as a developing country experienced changing and urbanising conditions, the population increased from 10.3 million in 1956 to 39.154 million in 2008. Population of Greater Khartoum-the capital- also increased rapidly from just over half a million in 1956 to 6.8 million in 2014 with estimated growth rate as 2.7% (Khartoum State (2015). The population influx caused a severe housing problem and a massive housing demand in a country, 46.5% of its population are under the poverty line (Sudan census,2008). That means half the population have inadequate income to afford living and housing.

The review of the Sudanese housing policies shows that those policies encompass two main types of programs. The first one addresses the needs of all sectors of the population by provision of plots through site and services schemes -an application of the enabling approach. The second type provides small built core units for low- income families. However, the recorded built core units in Greater Khartoum in the period 1961 -1996 by both public and private sectors are only around 2000 units which represents a few portions of the need for new housing at that time (see table (1)).

<table>
<thead>
<tr>
<th>town</th>
<th>location</th>
<th>Developer</th>
<th>Dwelling Type</th>
<th>Year</th>
<th>No. of Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khartoum</td>
<td>Al Shabiya</td>
<td>Public</td>
<td>Semi-Detached House</td>
<td>1961-1963</td>
<td>1048</td>
</tr>
<tr>
<td>Omdurman</td>
<td>Al Omeda</td>
<td>Public</td>
<td>Row Houses</td>
<td>1974</td>
<td>17</td>
</tr>
<tr>
<td>Omdurman</td>
<td>Al Omeda</td>
<td>Public</td>
<td>Detached House</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>Khartoum</td>
<td>HAJ yousif</td>
<td>Public</td>
<td>Detached House</td>
<td>-</td>
<td>32</td>
</tr>
<tr>
<td>Khartoum</td>
<td>Haj yousif</td>
<td>Public</td>
<td>Detached House</td>
<td>1975</td>
<td>107</td>
</tr>
<tr>
<td>Omdurman</td>
<td>Al Thoura</td>
<td>Public</td>
<td>Detached House</td>
<td>1975</td>
<td>123</td>
</tr>
<tr>
<td>Khartoum</td>
<td>Jebra</td>
<td>Public</td>
<td>Semi-Detached House</td>
<td>1975</td>
<td>200</td>
</tr>
<tr>
<td>Omdurman</td>
<td>Daralsalam</td>
<td>Private</td>
<td>Detached House</td>
<td>1990</td>
<td>250</td>
</tr>
<tr>
<td>Omdurman</td>
<td>Abu Said</td>
<td>Private</td>
<td>Detached House</td>
<td>1990</td>
<td>100</td>
</tr>
<tr>
<td>Khartoum</td>
<td>Jebra</td>
<td>Private</td>
<td>Flat</td>
<td>1993</td>
<td>24</td>
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<tr>
<td>Khartoum</td>
<td>Al Amarat</td>
<td>Private</td>
<td>Flat</td>
<td>1995</td>
<td>80</td>
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<tr>
<td>Khartoum</td>
<td>Al Mamora</td>
<td>Private</td>
<td>Flat</td>
<td>1996</td>
<td>120</td>
</tr>
<tr>
<td><strong>Total No. of Units</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2145</strong></td>
</tr>
</tbody>
</table>

After 1996 the state of Khartoum took serious actions to solve housing problem and established a new body: The State Fund for housing and development (The State Fund), which is created to address housing deficits through provision of more core units, table (2) shows housing projects built by the State Fund in the three towns Khartoum, Khartoum North and Omdurman (1996-2015). The built core units are more than one million.

Table (2) Housing projects built by the State Fund (1996-2015)
source: (the State Fund archives)
<table>
<thead>
<tr>
<th>Town</th>
<th>location</th>
<th>Start of construction</th>
<th>Number of units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khartoum</td>
<td>El Andalus 17</td>
<td>1996</td>
<td>2271</td>
</tr>
<tr>
<td>Khartoum</td>
<td>El Andalus 20</td>
<td>2001</td>
<td>2439</td>
</tr>
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<td>El Andalus 23</td>
<td>2001</td>
<td>855</td>
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<tr>
<td>Omdurman</td>
<td>El Thowra 71</td>
<td>2003</td>
<td>984</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Thowra 72</td>
<td>2003</td>
<td>1818</td>
</tr>
<tr>
<td>Khartoum North</td>
<td>El Tilal 1</td>
<td>2003</td>
<td>877</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Thowra 75</td>
<td>2004</td>
<td>3600</td>
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<tr>
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<td>El Thowra 73</td>
<td>2005</td>
<td>924</td>
</tr>
<tr>
<td>Khartoum North</td>
<td>El Wadi AlAkhdar 15</td>
<td>2006</td>
<td>828</td>
</tr>
<tr>
<td>Khartoum North</td>
<td>El Wadi AlAkhdar 20</td>
<td>2006</td>
<td>995</td>
</tr>
<tr>
<td>Khartoum North</td>
<td>El Wadi AlAkhdar 21</td>
<td>2006</td>
<td>1243</td>
</tr>
<tr>
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<td>El Thowra North 75</td>
<td>2007</td>
<td>154</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Thowra North 76</td>
<td>2007</td>
<td>638</td>
</tr>
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<td>Omdurman</td>
<td>El Thowra 99</td>
<td>2008</td>
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</tr>
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<td>El Thowra 101</td>
<td>2009</td>
<td>1371</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Thowra 102</td>
<td>2010</td>
<td>2096</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Thowra 103</td>
<td>2010</td>
<td>1685</td>
</tr>
<tr>
<td>Khartoum</td>
<td>El Safwa 4</td>
<td>2011</td>
<td>2686</td>
</tr>
<tr>
<td>Khartoum</td>
<td>El Safwa 5</td>
<td>2011</td>
<td>2505</td>
</tr>
<tr>
<td>Khartoum</td>
<td>El Safwa 6</td>
<td>2011</td>
<td>2444</td>
</tr>
<tr>
<td>Khartoum</td>
<td>El Safwa 7</td>
<td>2011</td>
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</tr>
<tr>
<td>Khartoum</td>
<td>El Safwa 15</td>
<td>2011</td>
<td>1110</td>
</tr>
<tr>
<td>Khartoum</td>
<td>El Safwa 11</td>
<td>2011</td>
<td>945</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Thowra West 80</td>
<td>2012</td>
<td>2422</td>
</tr>
<tr>
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<td>El Fath 2</td>
<td>2014</td>
<td>2189</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Fath 8</td>
<td>2014</td>
<td>1170</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Fath 13</td>
<td>2014</td>
<td>2149</td>
</tr>
<tr>
<td>Omdurman</td>
<td>El Fath 12</td>
<td>2014</td>
<td>2189</td>
</tr>
<tr>
<td><strong>Total No. of Units</strong></td>
<td></td>
<td></td>
<td><strong>1,038,911</strong></td>
</tr>
</tbody>
</table>

**Research Methodology**

The research was based on literature review and field survey, it had followed qualitative and quantitative methods which included: Plans and photos documentation, observation, interviews with senior officials at ministry of Physical Planning and the State Fund, and some inhabitants of the selected housing projects. Four low-cost housing projects were selected as case studied, they are constructed in different periods of time: New Deims in 1949, El Shabyia in 1963-1985, Al Iskan in 1975 and Elthora hara 72 in 2003. Data was collected from secondary data concerning old housing projects (New Deims, El Shabyia and Al Iskan) and primary data –field survey- for the new housing project (Elthora hara 72). The analysis was focused on comparison between the selected low-cost housing projects describing their size of the project, the target group of inhabitants, the design of the core unit and the construction including building materials and technologies.

**Presentation of Case Studies**

*New Deims Resettlement Project*
New Deims is located in Khartoum town, it lies outside the Railway Ring, south of the light Industrial area. The resettlement project was carried out in 1949. New Deims comprises 1233 dwellings of 200 square meter. The core unit contains two bed-rooms, a veranda, a kitchen, a toilet and a shower (see figure 2).

![Diagram of New Deims core unit](image)

**El Shabyia Project**

El shabyia is located in Khartoum –North. It was developed between 1963-1985 to provide housing for the workers from Khartoum- North industrial area. Around 1048 houses were constructed. There were two types of houses: Small Dwelling in plots of 252, 261 or 290 sq. m and large Dwelling in plots of 300, 310 or 340 sq. m. The core unit contains three bed-rooms, two verandas, a kitchen, a toilet and a shower. (see figure 3).

![Diagram of El Shabyia core unit](image)

**Figure (2) plan of the core unit - New Deims.**  
**Source:** Ministry of Physical Planning archives

**Figure (3) plan of the core unit - El shabyia.**  
**Source:** Daiffalla (1998)
**Al Iskan Project**

Al Iskan Project is located in West-South of Khartoum town-Jebra Block Three. The project started in 1975. It includes about 200 prototypes houses. Plots are 200 m². The core unit contains three bed-rooms, two verandas, a kitchen, a toilet and a shower (see figure (4)).

![Figure (4) plan of the core unit - Al Iskan Project.](image)

Source: Ministry of Physical Planning archives

**Elthora hara 72 Project**

Elthora hara 72 is located North-West of Omdurman in Karari locality. The project is constructed by the State Fund, it was started in 2003 and contains 1818 houses. The project contains three types of dwellings:

- **Low-cost housing (for low income families):** A core unit consists of one bed room, a kitchen and a toilet (see figure (5)). This type of housing holds 58% of the project - 674 houses.
- **Economic housing (for middle income families):** A core unit consists of one bed room, a kitchen and a toilet. It holds 37% of the project - 410 houses.
- **Investment housing (for high income families):** A villa consists of two rooms, a kitchen, a bathroom and living area. The construction of the house permits vertical expansion. It holds 5% of the project - 62 houses.
Discussion

The size of the project

Low-cost housing projects started as resettlement projects in New Deims, which was a native lodging area built to accommodate the working people building the newly occupied Capital-Khartoum. At the time of Resettlement (1949) there were five thousand houses accommodating some seventeen thousand people, who lived in conditions of terrible overcrowding. There were two reasons for the resettlement, firstly, housing condition in the Old Deims were seriously inadequate for the minimum requirements of decent family living and secondly, Old Deims blocked the expansion southward of Khartoum. The district authorities at that time were not equipped for an extensive scheme of housing loans or governments subsides which would have required special funds and organization. In the sixties, the housing authorities-built houses for the poor workers families in El Shabyia, the number of houses was large – 1048 units. In the seventies a small experimental Project- Al Iskan was built for low-income groups, only 200 houses were constructed.

The big change in projects size occurred after the establishment of the State Fund, it had an expanded social housing programme providing more than one million units. Those projects held the potential to improve the construction industry and help economic development of the country. The housing authorities became more organised and had reasonable budgets but at the same time the housing problem exaggerated and the demand for housing increased.

The increase in the projects size requires more vacant land which is available at the suburb of the capital so that new housing projects were located in remote areas, in which inhabitants are not well connected to jobs and to decent basic and social services Another important disadvantage in providing these large projects is the absence of demonstration projects, all housing projects were constructed without pilot projects to test sustainable practices and after completion there was no evaluation for the implemented housing projects so as to pick out the advantages and avoid the drawbacks.
**The Target group of inhabitants**

In the first resettlement project- New Deims- housing authorities recognised the important role of the social sustainability; therefore, they conducted a comprehensive social survey. By doing so they emphasized the role of housing as a social structure that considers socio-economic interactions of the inhabitants and their social qualities. The housing authorities tried to conserve the community structure because on the social side, Old Deims comprised of well-integrated communities, sharing certain loyalties, and exchanging certain mutual obligation. The housing authorities distributed plots to the inhabitants Old Deims, according to two fundamental criteria: permanent employment and ten years occupation. It was, however, recognized from the social survey that some families-29- were qualified for plots, but who could not build without substantial assistance, such families were given financial assistants and were left to their own devices. After that eligibility criteria for obtaining a house in El Shabyia project changed to focus on nationality -Sudanese, family size -five persons, employment -public sector and salary. The beneficiaries were required to deposit down payment, equal to 10% of the total cost of the house and the services provided. The balance was to be paid in instalments over a period of 20 years. In Al Iskan Project core housing units were allocated to all low-income families living in the capital without specifying working in the public sector. families were ranked according to certain social and economic criteria (the point system). The beneficiaries were required to pay the total official nominal price of the house without instalments.

The state fund provided housing for mixed inhabitants in most projects, hence Elthora hara 72 project was intended for different income levels but the majority were low-income families - 58% of the total number of the inhabitants (see Figure (6) and (7)). This new policy enables cohesion and interaction of different social classes in the same community, and most importantly all the inhabitants would have equitable access to basic and social services. Most probably the social mix will lead to social sustainability. Distribution of low-cost units were governed by rules- a point system- and a board to insure the merit of the applicant. The beneficiaries were required to deposit down payment, equal to 20% of the total cost of the house and the services provided. The balance was to be paid in instalments over a period of 12 years. Although the down payment was large but the instalments were affordable for the poor families.

![Figure (6): Panoramic view of the Investment Houses of Elthora hara 72](source: (the State Fund archives))

![Figure (7): Panoramic view of the low-cost Houses of Elthora hara 72](source: (the State Fund archives))

**The design of the core unit**

Traditionally, the two basic types of dwellings are either houses or flats, in Khartoum the popular dwelling type is the single detached house. The choice of houses as a predominant
dwelling type had led to horizontal expansion and urban sprawl of the capital, low densities, and made basic urban services unaffordable. Although flats permit vertical expansion but they were not popular because of many reasons: the climate, the great desire for privacy, the large size of families, traditional tendencies and lack of supportive basic services especially sewerage.

Most of low-cost projects have semi-detached houses, although the use of raw houses would have many advantages such as saving in areas and building materials. In New Deims and El Shabyia project, the design of the built area is semi-compact. the built area was 64.5 m² in New Deims and it was enlarged to 91 m² in ElShabyia project. As a new housing experiment, the design of the core unit in Al Iskan Project changed to be compacted and the built area was reduced to 38.4 m². In Elthora hara 72 the design of the core unit was scattered and the built area was reduced again to 30.0 m².

It is noticeable that although the plot area of the house increased a little from 200 m² to 240 m², but the built area of the core units decreased from 91 m² to 30 m² and the percentage of the built area also decreased from 32% to 15% (see table (3)). The reason behind this phenomenon is that the land in Sudan by constitution belongs to the government and its cost considered zero in the financial break down of the cost of the house, while the cost of the construction of the core-unit is considered high according to the financial ability of the public sector, so that the increased demand of housing units leads to provision of large quantities of core units with small built areas.

As the choices made for design and planning need to be derived from the specific context and climate of the community (UN-Habitat 2012), all designs of the core units in the four selected projects tried to their best to respect traditions and lifestyles of the inhabitants by separating the living area of the family and the guests and segregating males and females whenever the size of the built area permits. They also provided (by the location of the built area) possibilities for dividing the courtyard into two sections, front yard for males and back yard for females (see Figure (8) and (9)). The authorities provided proposals for future extensions - incremental development- of the core-unit but most inhabitants didn’t follow these proposals and developed houses according to their needs and financial abilities.

Table (3) Relationship between the size of projects, the plot areas and the built areas.
Source: (the researcher)

<table>
<thead>
<tr>
<th>Project</th>
<th>Size of the project</th>
<th>Plot area (m²)</th>
<th>Built Area</th>
<th>Percentage of built area</th>
<th>House type</th>
<th>Design type</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Deims</td>
<td>1233</td>
<td>200</td>
<td>64.5</td>
<td>32%</td>
<td>Semi-Detached</td>
<td>Semi-compact</td>
</tr>
<tr>
<td>El Shabyia</td>
<td>1048</td>
<td>252 - 290</td>
<td>91</td>
<td>30%</td>
<td>Semi-Detached</td>
<td>Semi-compact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300- 340</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al Iskan Project</td>
<td>200</td>
<td>240</td>
<td>38.4</td>
<td>16%</td>
<td>Semi-Detached</td>
<td>compact</td>
</tr>
<tr>
<td>Elthora hara 72</td>
<td>1818</td>
<td>200</td>
<td>30</td>
<td>15%</td>
<td>Semi-Detached</td>
<td>Scattered</td>
</tr>
</tbody>
</table>
Sustainable building materials and practices

In New Deims houses were built with sustainable traditional materials and applied indigenous knowledge and techniques in construction of houses which are affordable and environmentally friendly as walls were built with jaloos (i.e. rammed earth or cob) and houses were roofed with timber. The construction of houses was carried out by the inhabitants themselves helping each other’s-public participation- without intervention of the housing authorities. The inhabitants were advised to collect all wood work, wooden beams and the like from their demolished houses, and to use them in their new houses, so that the building materials were recycled. Unfortunately, the houses were un-durable and couldn’t resist climatic conditions e.g. rains and storms.

In the following projects, design, construction and distribution of the houses were undertaken by the public authorities. In El Shabyia project, the authorities used more durable building materials so that houses were constructed with plain concrete foundations and cement block walls but roofed with asbestos corrugated sheets which was found to be unsafe for health (WHO 2011). More elaborated building materials and technologies were used in Al Iskan Project. The houses were constructed with grade beam of concrete in the foundation and load bearing walls with burned bricks. concrete slabs were used for roofs for the first time in housing projects. In spite of the fact that concrete slabs are more expensive than traditional local types of roofs (corrugated iron sheets or timber) but they are more durable and can resist climatic conditions, therefore increase the life span of the houses.

The first construction technologies for the houses in The Fund projects started with the use of sustainable local traditional materials such as green bricks which has a small ecological impact, afterwards they used materials produced with imported technologies such as cement blocks. Therefore, in Elthora hara 72, the houses were constructed with strip foundations made of stone and cement block walls, roofed with concrete. The planning and design of the core units are prepared by Ministry of Physical Planning and The Fund handles construction and distribution of houses. It is noticeable that Mass production of house units by the fund contributed to the development of the building industry, by establishment and support of on-site factories for building materials manufacturing and provided employment opportunities for local workers from nearby areas (see Figure (10) and (11)). The important question is: In spite of the availability of multiple different sustainable construction materials which are used across the country with smaller ecological impacts than imported materials why the State Fund did not use them in construction of housing projects. One popular example is the
stabilized soil blocks which enable zero consumption of firewood and structural timber, and 60% decrease in water usage. They are used in building houses for refugees in Darfur because they have many advantages such as: 30% more affordable than fired brick and faster to build. It is chosen among ten good practices of sustainable construction materials world-wide (UN Habitat 2012).

**Conclusion**

A comprehensive housing approach should include not only economic, cultural, social and environmental but also institutional sustainability aspects. Sustainable housing projects require comprehensive plans to attain pre-defined goals. It is clearly observed that housing policy for the poor people in Sudan has adopted a separate approach that dealing with housing problem isolated from other development issues, and ignoring the social, cultural, environmental and economic aspects of housing.

In New Deims resettlement project a comprehensive social survey was carried out. It covered cultural values, norms and traditions of the inhabitants as well as the life styles and behaviour, so that the proposed design of the core-unit was satisfactory for the occupants. The construction of the houses was made by the inhabitants themselves. Afterwards, in the following projects the inhabitants were excluded from the process of the design and the construction of the houses, their contribution started after settling in the neighbourhoods and participated in providing social services e.g. schools, mosques, health centres, etc. according to their needs.

Regarding the built area, as the size of housing projects enlarged (e.g. Elthora hara 72) the size of the built unit decreased, so as to serve a large amount of poor families. The reduction of the built unit makes it inefficient since most of poor families have large family size. Former projects (New Deims, Al Iskan Project and El Shabyia) provided one or two prototypes of core-units for low-income families only but new projects of The state fund provides more options of affordable housing across different income levels to offer housing to households with varying needs and abilities.

The experience of Sudan in providing built houses for low-income families is not financially and technically appropriate. Still there is a need for more incentives for the private sector to invest in construction of low-cost housing under the supervision of the public authorities and within the framework of sustainable housing, and new affordable financial mechanisms to support the low level of construction by low interest loans. Moreover, there
are possibilities of application of different sustainable technologies such as: ecological retrofitting, renewable energy and forms of saving water which are essential in providing sustainable housing.

If the public authority is sincerely interested in the sustainable housing development its decision and actions would be flexible, adaptable and creative, to develop a simple and integrated approach regarding how to produce sustainable housing. Production of sustainable housing need to be addressed in three different levels: At policy/authority level to help local authorities to formulate housing polices to match sustainable development goals and objectives, at community level to enable community representative to participate in the project planning and decision making and at family level to enable the inhabitants to upgrade their housing according to their individual needs and capacity.

References

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Social Shifts - Living in Gated Communities: A Case of Andalucía, Jordan

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Abstract: In global surge of neoliberal urban restructuring and emerging forms of spatial ordering, Amman stands witness to isolated urban development. Upper-end residential gated communities are faced with as much controversial debate as do their global counterparts. For some, they represent icons of post-consensus, fragmenting civic society, enclosing and excluding by walls and gates. For others, they are an efficient way of organizing urban development. Contested are issues and values of integration versus fragmentation, public versus private, inclusion versus exclusion, actual insecurity versus perceived insecurity. Andalucía is the first and one of few gated communities to be found in Jordan.

This research aims to investigate inhabitants’ motives for deciding to live in the gated community of Andalucía, Amman. Relating to factors established as reasons for making the decision to live in gated communities, the paper employed a survey research design investigating the agreement of motives with such factors. A structured questionnaire was administered in the context of face-to-face structured interviews. The total sample size was 100 subjects. The study hypothesized that the decision to live in a gated community is motivated by a set of factors including: security, privatization, prestige, lifestyle, and economic feasibility.

Results indicated significant effects for the following factors: total governance and total prestige. As well as significant effects for the following subcomponents: governance of landowner committee, governance of infrastructural services, image and exclusivity, supporting sense of community, and provision of amenities. The interactive relationship for the set of variables with decision to live in a gated community was reported significant. Contribution of each variable to the interactive model was only significant for total governance. The order of strength of contribution to the model from highest to lowest as follows: Total Governance, Total Economic Feasibility, Total Security, Total Prestige, and Total Lifestyle.

Keywords: Gated, Community, Jordan, Social, Shifts

Introduction

Glasze et al. (2006) state that, although not a new phenomenon, gated communities received much public attention since only late 1990s. Gated communities refer to the type of housing development which is physically secured and often privately organized. Gated communities are faced with as much lively and diverse debate as do their global counterparts. For some, they represent icons of post-consensus, fragmenting civic society, enclosing and excluding by walls and gates. For others they are simply an efficient way of organizing urban life (Glasze et al., 2006).

Challenged are issues and values of integration versus fragmentation, public versus private, inclusion versus exclusion, actual insecurity versus perceived insecurity (Flanagan, 1990; Blakely & Snyder, 1997; Glasze et al., 2006; Daher, 2013). One of the main issues argued is the effect that gating might have on equity and integration of the overall society (Blakely & Snydre, 1997; Low, 2006; Roitman, 2007). Blakely and Snyder (1997) argue how
restricted access in gated communities makes public spaces private. Although private land-use controls is not new, gated communities may be perceived as a new form of social ordering, promoting safety and exclusivity for the privileged few (Low, 2006). The majority of gated communities found today are middle to upper-middle class (Blakely & Snydre, 1997). This supports the notion that, for a certain fragment of society, gated communities can be simply an efficient way of organizing urban life (Glasze et al., 2006).

Exploration of motives is multi-disciplinary and targets different groups of interest, including decision makers, developers, or inhabitants (Blakely & Snyder, 1997; Janoschka & Borsdorf, 2006; Touman, 2005; Glasze et al., 2006). For developers, gated communities can be a marketing issue, another way to target specific sub markets, or a necessity to meet demand (Blakely & Snydre, 1997). Motives, especially, inhabitants' motives may differ greatly from one community to another (Janoschka & Borsdorf, 2006; Glasze et al., 2006).

In global surge of neoliberal urban restructuring and emerging forms of spatial ordering, Amman stands witness to high-end and isolated urban development (Daher, 2013). Upper-end residential gated communities are of the most evident examples. Andalucía is the first and one of few gated communities to be found in the city of Amman. An understanding of the reasons that influenced residents to choose to live in this new urban form is essential not only to comprehend rationale of the case of Andalucía, but also future developments as well as possible alternative forms. Accordingly, this paper aims to investigate inhabitants’ motives for deciding to live in the gated community of Andalucía utilizing a survey research design.

**Research Setting**

Andalucía is the first gated community in Jordan. It is located about 20km from the capital of Amman towards Madaba. It consists of about 588 villas with 10 varying prototypes. The main developers are TAAMEER Jordan/Jordan Company for Real Estate Development. Major funding for this development originally came from the United Arab Emirates. The cost per square meter reached about 800 JDs for the residential villas (Daher, 2013). The villas built-up areas ranged from 312sqm to 661sqm, residing on plots that range from 496sqm to 1,020sqm. The area covered by the built up takes up assumingly 17% of the total land area, leaving about 73% of the land as open space. This open space included parks, streets, sidewalks and yards for each housing unit. The central amenities included health club, clinic, shopping centre, restaurants, coffee shops, and parks (TAAMEER, 2015).

![Figure 1. Aerial Image of Andalucía Gated Community (Google Earth, 2015).](image-url)

The project was supposed to be completed in 2009, at a total cost of 150,000,000 JDs; but due to cash flow problems the project had delays in completion and a failure by TAAMEER to pay contractors and suppliers. In 2013, the project picked up again and was
fully operational in relevance to residential units, but there was a delay in delivering the central space of amenities. The same year witnessed the elections of the first landowner's committee planned to locally manage the project (TAAMEER, 2015).

Literature Review

Bagaeen and Uduku (2010) assert how attempts at creating defensible space are worthy of attention. Several alternative forms are developed which provide many solutions that are either similar in efficiency to those provided in gated communities and represent main basis for selection, or provide a constructive alternative to the deficiencies provided by the physical gating of communities. Not only are these alternatives operational but have been proven successful as well (Newman, 1996; Lang & Danielsen, 1997; McKenzie, 1994; Bagaeen & Uduku, 2010).

Inhabitants Decision

Empirical research was used to examine the motivations and desires behind the decision to live in private communities (Sheinbaum, 2010). Housing is a special good in so far as nobody really can abstain from consuming it. Choice is highly dependent on financial, cultural, and social capital (Webster & Glasze, 2006). Explorations from diverse contexts around the world reveal different processes and influences affecting the decision to move and live in a gated community (Janoschka & Borsdorf, 2006; Touman, 2005; Low, 2006; Dupuis & Dixon, 2010). Lang and Danielsen (1997) indicated that gated community phenomenon is merely a developer’s marketing device to create the appearance of security as an amenity and as a wise investment. Low (2006) mentions local context and politics, the history of the community and urban growth, as influences to the residents’ decisions. In comparing influences of media and motives of inhabitants, Janoschka and Borsdorf (2006) despite media discourse and marketing emphasis, which stress certain factors (such as fear or prestige), decision made by inhabitants to move into gated communities is often motivated by face-to-face propaganda, group behaviour, or simply personal knowledge.

Gated Communities Causality and Motivation

There are many regional variations in the style and extent of private neighbourhoods that are not explained (Webster & Glasze, 2006). Explorations of the motivation for the formation and spread of gated communities lacked clear factual information, ethnographic examination, and systematic fieldwork (Frantz, 2006; Glasze et al., 2006; Low, 2006). There are various reasons and influences for the emergence of this urban form, and it depends on the circumstances of each gated community (Touman, 2005; Glasze et al., 2006).

Security

Growing criminality is often assumed to be the major or single cause for the spread and emergence of gated communities (Blakely & Snyder, 1997; Touman, 2005; Glasze et al., 2006; Sardar, 2010). Blakely and Snyder (1997) state that security zones are possibly the fastest growing type of gated community, arguing that fear of crime and outsiders is the major motivation for defensive settlements. Sardar (2010) asserts that securing the privilege presented by wealth is the sole selecting criterion of membership. Frantz (2006) further labelled it a kind of landscape of fear, referring to the association of gated communities with control and security. Blakely and Snyder (1997) affirm how gates attempt to protect property, property values, and wall out possible crime. According to Frantz (2006) security measure are employed through a series of defensive means of architectural and
landscaping natures. They include physical means through gates, walls, and fences or technical protection through security guards and patrols, and high-tech surveillance systems. Roitman (2007) states how these physical gates or barriers which deter access are often justified on the grounds of more security within. Lang and Danielsen (1997) further stress how the walls and gates provide physical as well as psychological security.

Privatization (Governance)
Through privatized governance and associations, gated communities are providing their own security, infrastructure, maintenance services, and facilities. These services are traditionally public goods (Blakely & Snyder, 1997). Many studies show that the secured provision of high-quality infrastructural services (electrical power, water, and communication) play a crucial role in making private and gated housing estates attractive to home-buyers (Webster & Glasze, 2006). Having a better standards of living and a wider range of services are equally motivational (Low, 2006). Privatization is identified as the desire to replace and internally control public services that the public sector cannot provide (Blakely & Snyder, 1997; Webster & Glasze, 2006; Wehrhahn & Raposo, 2006). Gated communities are growing as a response to the public government’s failure to provide adequate neighbourhood services. This is not only evident in the failure and deficiency of public governance to provide the quality and quantity of demanded civic goods, but also in the fact that local governments are benefiting from these private communities, as they enhance their tax base without providing additional services (McKenzie, 1994).

Prestige
Gated communities may attract inhabitants as it symbolizes distinction and prestige (Blakely & Snyder, 1997). This motivation is seen as the most traditional one, for gates are seen as protecting economic and social status. Symbolizing prestige and status is developed even further than the majestic gates; carefully controlled aesthetics and often enviable landscapes are main features of this urban form (Frantz, 2006). Exclusion is another dimension of attraction to gated communities; strict access reserved for residents and their visitors is demonstrated as a form of social differentiation (Touman, 2005; Wehrhahn & Raposo, 2006; Roitman, 2007; Bagaeen & Uduku, 2010).

Lifestyle
Many gated communities are seen as lifestyle communities; as the gates provide security and separation for leisure activities and amenities (Blakely & Snyder, 1997). Residents’ primary motivation is the amenities provided, and security measures established for the control of these amenities. The wider range of amenities is seen to enhance the quality of life (Low, 2006). Lifestyle is also seen as a motive because of the desired social coherence and homogeneous environment, as well as the desire and need for a sense of community (Janoschka & Borsdorf, 2006; Touman, 2005).

Economic Feasibility
Foldvary (2006) sees the growth of private neighbourhoods as an empirical proof of the economic feasibility of private governance. As the financing of territorial civic goods from rentals generated by these goods is a most economically feasible base. Accordingly, gating may be seen to be motivated by a desire to invest in the future (Blakely & Snyder, 1997). Frantz (2006) further demonstrates how houses in gated communities are expected not to be vulnerable to value fluctuation as in conventional communities. In principle gated
communities are less of a risky investment. McKenzie (1994) affirms that restrictions within gated communities exist only for maintaining property values.

Research Methods

A survey research design was followed to conduct this study. A structured questionnaire was administered in the context of face-to-face structured interviews. The study hypothesizes that the decision to live in a gated community is motivated by a specific set of factors: security, privatization, prestige, lifestyle, and economic feasibility. Data was collected through one-to-one interview.

Population of the study and Sample

The target population of the study are residents of the gated community of Andalucía in Amman. Thus the total sample size was determined to be 100. Both male and female subjects from each household were targeted. Because the families are dispersed along different and distant locations through the setting and no distinct street map was available; snowball sampling technique was employed in order to select subjects that were available and willing to participate. Participation was voluntarily.

Variables

Dependent Variable and Measure: Decision to live in a gated community

Based on the reviewed literature presented above, the dependent variable (Decision to live in a gated community) was defined as the influence on making the decision to live in a gated community. The variable was measured using a dichotomous nominal measure; whether the decision was influenced by media or others or was not influenced by any external factor (self decision).

Independent Variables and Measures

The independent study construct is the motive residents hold for deciding to live in a gated community. This construct was defined by five variables which are: security, privatization, prestige, lifestyle, and economic feasibility. Each defined sub-variables was measured using a 5-point Likert scale: 5 (strongly agree) to 1 (strongly disagree). The five variables are operationally defined by the following measurable sub-variables:

1. Security: the desire for physical and nonphysical symbolic security measures: (a) Desire for security through restrictive access controls (gates, walls, and fences). (b) Desire for provision of security through guards and/or surveillance systems.
2. Privatization (Governance): the desire for privatized services through three different sub factors: (a) Private governance through landowners’ committee. (b) Provision of high-quality infrastructural services (electricity, communication, and water). (c) Availability of green and open spaces.
3. Prestige: two sub factors defining prestige are: (a) Image and the quality of exterior features. (b) Exclusivity.
4. Lifestyle: sub factors supporting a certain lifestyles include: (a) Supporting a sense of community. (b) Provision of amenities (health club, restaurants, and cafes). (c) Provision of activities.
5. Economic feasibility: many sub factors could effectively contribute to the economic feasibility of the selected housing: (a) Appealing price. (b) Investment opportunity. (c) Maintaining property value. (d) Facilitated bank loans.

Analysis and Discussion

**Overall model with decision to live in a gated community:**

A regression test was carried out to test the total interactive model. The interactive relationship of the set of variables with decision to live in a gated community is reported significant in Table (1). This suggests that all factors work together towards making the subjects decision to move to a gated community.

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>5.75</td>
<td>5</td>
<td>1.15</td>
<td>5.80</td>
<td>.00</td>
</tr>
<tr>
<td>Residual</td>
<td>16.65</td>
<td>84</td>
<td>0.198</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22.40</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As well, contribution to the decision to live in a gated community within the interactive model was significant only by total governance \[t (5, 89) = 3.987\], \(P < 0.05\). The order of strength of contribution in the model from highest to lowest as follows: Total Governance, Total Economic Feasibility, Total Security, Total Prestige, and Total Lifestyle. On the other hand, Total Security seems to contribute to the model in a negative direction, Table (2). This suggests the less they feel secure the more it affects their decision to move to a gated community, which makes sense.

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>-0.16</td>
<td>0.48</td>
<td>-0.33</td>
<td>0.74</td>
</tr>
<tr>
<td>Total Security</td>
<td>-0.06</td>
<td>0.05</td>
<td>-0.11</td>
<td>-1.07</td>
</tr>
<tr>
<td>Total Governance</td>
<td>0.29</td>
<td>0.08</td>
<td>0.44</td>
<td>3.99</td>
</tr>
<tr>
<td>Total Prestige</td>
<td>0.05</td>
<td>0.06</td>
<td>0.11</td>
<td>0.98</td>
</tr>
<tr>
<td>Total Lifestyle</td>
<td>0.06</td>
<td>0.08</td>
<td>0.09</td>
<td>0.75</td>
</tr>
<tr>
<td>Total Economic Feasibility</td>
<td>0.08</td>
<td>0.06</td>
<td>0.13</td>
<td>1.21</td>
</tr>
</tbody>
</table>

Further, in order to test the major study hypothesis the following sub-hypotheses testing was carried out:

**Sub-Hypothesis 1: ONEWAY ANOVA - The decision to live in a gated community is affected by security:**

A One way ANOVA was carried out to test the difference in the mean of scores of decision to live in a gated community with the mean of scores of: total security, total governance, total prestige, total lifestyle, and total economic feasibility. Results are presented in Tables (3) and (4).

<table>
<thead>
<tr>
<th>Model</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Security</td>
<td>48</td>
<td>3.13</td>
<td>1.05</td>
<td>0.15</td>
</tr>
</tbody>
</table>
The test indicated no significant effect of total security and its physical and symbolic components, Table (4).

Sub-Hypothesis 2: ONEWAY ANOVA – The decision to live in a gated community is affected by privatization (governance):

A One way ANOVA was carried out to test the difference in the mean of scores of decision to live in a gated community with the mean of scores of: total governance, governance of landowner committee, governance of infrastructural services, and governance of availability of green space. Results are presented in Tables (5) and (6).

Table 5. Descriptive Analysis - Governance and its Components

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Governance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>3.38</td>
<td>0.72</td>
<td>0.10</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>4.07</td>
<td>0.57</td>
<td>0.09</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.70</td>
<td>0.74</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Governance - Landowner Committee</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>2.44</td>
<td>1.01</td>
<td>0.15</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>3.79</td>
<td>0.87</td>
<td>0.13</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.07</td>
<td>1.16</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Governance - Infrastructural Services</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>3.19</td>
<td>1.25</td>
<td>0.18</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>4.00</td>
<td>0.94</td>
<td>0.15</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.57</td>
<td>1.18</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Governance - Availability of Green Space</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>4.50</td>
<td>0.79</td>
<td>0.12</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>4.43</td>
<td>0.83</td>
<td>0.13</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>4.47</td>
<td>0.81</td>
<td>0.09</td>
</tr>
</tbody>
</table>
The test indicated a significant effect of total governance with decision to live in a gated community; in addition to governance of landowner committee and governance of infrastructural services. However, the effect of governance of landowner committee \([F (1, 89) = 45.42], P < 0.05\) was higher than the governance of infrastructural services \([F (1, 89) = 11.90], P < 0.05\), Table (6). This suggests that people are more encouraged to move to gated community because such committees are established as they will manage the private urban setting.

<table>
<thead>
<tr>
<th>Table 6. ONEWAY ANOVA - Governance and its Components by Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of Squares</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td><strong>Total Governance</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Governance</strong></td>
</tr>
<tr>
<td><strong>Landowner</strong></td>
</tr>
<tr>
<td><strong>Committee</strong></td>
</tr>
<tr>
<td><strong>Governance</strong></td>
</tr>
<tr>
<td><strong>Infrastructural Services</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Governance</strong></td>
</tr>
<tr>
<td><strong>Availability of Green Space</strong></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Sub-Hypothesis 3: ONEWAY ANOVA – The decision to live in a gated community is affected by prestige:**

A One way ANOVA was carried out to test the difference in the mean of scores of decision to live in a gated community with the mean of scores of: total prestige, image, and exclusivity. Results are presented in Tables (7) and (8).

<table>
<thead>
<tr>
<th>Table 7. Descriptive Analysis - Prestige and its Components (Image and Exclusivity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td><strong>Total Prestige</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Image</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Exclusivity</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

The test indicated a significant effect of total prestige with decision to live in a gated community; in addition to image and exclusivity were significant. However, the effect of
exclusivity \( [F (1, 89) = 4.98], P < 0.05 \) was higher than image \( [F (1, 89) = 3.15], P < 0.05 \), Table (8). This suggests that exclusivity has more importance for their decision than image.

Table 8. ONEWAY ANOVA - Prestige and its Components (Image and Exclusivity) by Decision

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Prestige</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>5.40</td>
<td>1</td>
<td>5.40</td>
<td>5.79</td>
<td>0.02</td>
</tr>
<tr>
<td>Within Groups</td>
<td>82.09</td>
<td>88</td>
<td>0.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>87.50</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Image</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>4.29</td>
<td>1</td>
<td>4.29</td>
<td>3.15</td>
<td>0.08</td>
</tr>
<tr>
<td>Within Groups</td>
<td>119.81</td>
<td>88</td>
<td>1.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>124.10</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Exclusivity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>6.65</td>
<td>1</td>
<td>6.65</td>
<td>4.98</td>
<td>0.03</td>
</tr>
<tr>
<td>Within Groups</td>
<td>117.46</td>
<td>88</td>
<td>1.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>124.10</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sub-Hypothesis 4: ONEWAY ANOVA – The decision to live in a gated community is affected by lifestyle, and economic feasibility:

A One way ANOVA was carried out to test the difference in the mean of scores of decision to live in a gated community with the mean of scores of: total lifestyle, supporting sense of community, provision of amenities, and provision of activities. Results are presented in Tables (9) and (10).

Table 9. Descriptive Analysis - Lifestyle and its Components

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Lifestyle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>3.83</td>
<td>0.89</td>
<td>0.13</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>4.05</td>
<td>0.49</td>
<td>0.08</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.93</td>
<td>0.74</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Supporting Sense of Community</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>4.06</td>
<td>0.76</td>
<td>0.11</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>4.43</td>
<td>0.63</td>
<td>0.09</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>4.23</td>
<td>0.72</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Provision of Amenities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>4.06</td>
<td>1.2</td>
<td>0.18</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>4.64</td>
<td>0.49</td>
<td>0.08</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>4.33</td>
<td>0.98</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Provision of Activities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>3.38</td>
<td>1.33</td>
<td>0.19</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>3.07</td>
<td>0.97</td>
<td>0.15</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.23</td>
<td>1.18</td>
<td>0.12</td>
</tr>
</tbody>
</table>

The test indicated no significant effect of total lifestyle with decision to live in a gated community. However, supporting sense of community and provision of amenities were significant. The effect of provision of amenities \( [F (1, 89) = 8.46], P < 0.05 \) was higher than supporting sense of community \( [F (1, 89) = 6.129], P < 0.05 \), Table (10). This suggests that people are looking more for urban goods.

Table 10. ONEWAY ANOVA - Lifestyle and its Components by Decision

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Lifestyle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>1.03</td>
<td>1</td>
<td>1.03</td>
<td>1.88</td>
<td>0.17</td>
</tr>
<tr>
<td>Within Groups</td>
<td>47.91</td>
<td>88</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sub-Hypothesis 5: ONEWAY ANOVA – The decision to live in a gated community is affected by economic feasibility:

A One way ANOVA was carried out to test the difference in the mean of scores of decision to live in a gated community with the mean of scores of: total economic feasibility, appealing price, investment opportunity, property value, and bank loans. Results are presented in Tables (11) and (12).

Table 11. Descriptive Analysis - Economic Feasibility and its Components

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Economic Feasibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>3.47</td>
<td>0.88</td>
<td>0.13</td>
</tr>
<tr>
<td>Free Willing</td>
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<td>3.64</td>
<td>0.86</td>
<td>0.13</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.55</td>
<td>0.87</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Appealing Price</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
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<td>4.13</td>
<td>0.79</td>
<td>0.11</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>4.36</td>
<td>0.61</td>
<td>0.09</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>4.23</td>
<td>0.72</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Investment Opportunity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
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<td>3.13</td>
<td>1.47</td>
<td>0.21</td>
</tr>
<tr>
<td>Free Willing</td>
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<td>3.07</td>
<td>1.40</td>
<td>0.22</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.10</td>
<td>1.43</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Property Value</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
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<td>3.19</td>
<td>1.19</td>
<td>0.17</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>3.57</td>
<td>0.91</td>
<td>0.14</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.37</td>
<td>1.09</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Bank Loans</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenced</td>
<td>48</td>
<td>3.44</td>
<td>1.89</td>
<td>0.27</td>
</tr>
<tr>
<td>Free Willing</td>
<td>42</td>
<td>3.57</td>
<td>1.52</td>
<td>0.23</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>3.50</td>
<td>1.72</td>
<td>0.18</td>
</tr>
</tbody>
</table>

The test indicated no significant effect of total economic feasibility with decision to live in a gated community. And only a marginal significance with property value [F (1, 89) = 2.860], P < 0.05, Table (12).

Table 12. ONEWAY ANOVA - Economic Feasibility and its Components by Decision

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Economic Feasibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>0.68</td>
<td>1</td>
<td>0.68</td>
<td>0.90</td>
<td>0.35</td>
</tr>
<tr>
<td>Within Groups</td>
<td>66.22</td>
<td>88</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>66.90</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Exploring Inhabitants’ Motives for Living in Gated Communities

Developers suggest that once a client becomes part of gated community exclusive community, they will have a utopian existence and become a completely transformed individual (Daher, 2013). Examples of marketing slogans of this real-estate development were “Providing distinctive homes that will redefine everyday life” and “the selling of paradise on the ground”. This suggests that exclusivity is the most important factors that can affects residents decision to move in. However, the real motives explored from the field interviews included the following:

1. **Factors for decision to move in:** Location, neighbours, facilities, future investment opportunity, escape from chaos of Amman, tranquillity, desire for privacy, convenient travelling distance, convenient for retirement, future investment, suitable for children, suitable for family lifestyle, summer or vacation house, a life’s dream, influence by others.

2. **Significance of such project:** independence, privacy, investment opportunity, price, services, convenient amenities, environment, sense of community, tranquillity, quietness, homogenous fabric, kind neighbours, fresh air, quality of people, safe for children, class, prestige, convenience, location, carefully planned neighbourhood, environment for family and friends.

### Conclusions

The following conclusions are revealed from the study:

1. The overall models with decision to live in a gated community: The interactive relationship of the set of variables with decision to live in a gated community was reported significant. As well, contribution of each variable on the decision to live in a gated community within the interactive model was significant only for total governance. Their order in the model from highest to lowest as follows: Total Governance, Total Economic Feasibility, Total Security, Total Prestige, and Total Lifestyle. On the other hand Total Security seems to contribute in a negative direction to the model.

2. Total security and its physical and symbolic components have no significant effect.

3. The decision to live in a gated community is affected by: (a) Privatization (governance): a significant effect of total governance; in addition to governance of landowner committee and governance of infrastructural services. However, the effect of governance of landowner committee was higher than the governance of infrastructural services. (b) Prestige: a significant effect of total prestige; in addition to image and
exclusivity. However, the effect of exclusivity was higher than image. (c) Lifestyle: although total lifestyle has no significant effect, supporting sense of community and provision of amenities has a significant effect. The effect of provision of amenities was higher than supporting sense of community. (d) Economic feasibility: although it had no significant effect, a marginal significance of property value is proved.

References


The Sustainable redesign of existing buildings in Greece: The case of existing, typical residences

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Abstract: Residential buildings in Greece form an important part of the existing building stock. Furthermore, most of these buildings were built prior to the first Thermal Insulation Code of 1981. The present paper focusses on existing, typical residences built after 1920, which are found mostly in suburban areas and settlements all around Greece and tries to evaluate the effect of simple bioclimatic interventions on the improvement of their diurnal, inter-seasonal and annual thermal performance. The applied strategies include thermal insulation of building shell and openings, and shading and natural ventilation for the summer period. The study was performed within the framework of the 6th semester undergraduate course of “Special Topics on Environmental and Bioclimatic Design” in the NTUA, School of Architecture. The course attempts to educate students on assessing the thermal characteristics and performance of existing buildings and then propose and quantitatively evaluate the effect of low-tech and low-cost interventions with the use of energy simulation software. The results of the study are two-fold and involve the assessment of simple bioclimatic interventions to existing buildings’ energy performance and thermal comfort conditions on one hand and the teaching outcome of the course on the other.

Keywords: Greece, Typical residences, Existing buildings, Bioclimatic upgrade, Thermal modelling

Introduction

The design of residences in suburban and rural areas is free of many of the constraints, which exist in urban centres. It allows the application of a number of bioclimatic features, and particularly favours, depending on the terrain and the orientation, the exploitation of the sun, as a means of passive solar heating, and the prevailing winds, for passive cooling. Consequently, the incorporation of passive and low energy architecture features to the design process is very important. The same applies for existing buildings, only in this case, design constraints, which in some cases may be important, also exist.

The demolition of existing buildings and their replacement with new, environmentally-friendly ones is not an economically, ecologically or socially sound alternative. Nowadays, it is clearer than ever that “the Greenest Building Is... One That Is Already Built” (Elefante, 2012). Furthermore, while savings and impact reductions may seem small when considering a single building, they can be substantial when scaled across the building stock of a city, or even a country (Elefante, 2012).

All the above are especially true for Greece, because of the grave economic crisis that the country has been facing during the last years. Consequently, the refurbishment of such buildings is a “one-way street”, as it not only helps preserve the energy initially embodied in them, but can also contribute to important energy savings for heating, cooling and lighting and, at the same time, significantly improve overall comfort conditions and quality of life. Finally, it can function as a prototype for architects, engineers and the general public on issues related to energy conservation and bioclimatic architecture.

In this paper, an attempt is made to assess the thermal performance of typical residences built after 1920 and until the application of the Thermal Insulation Code (1981),
which are found mostly in suburban areas and settlements all around Greece, and to investigate the effect of passive and low energy design features in energy refurbishment interventions. The study was performed within the framework of the 6th semester undergraduate course of “Special Topics on Environmental and Bioclimatic Design” in the School of Architecture of the National Technical University of Athens, Greece.

Characteristics of the building stock

Existing residential buildings in Greece show increased energy consumption, not only for cooling, which would be understandable, given the extended summer period that exists, especially during the last decades in Greece, but predominantly for heating. This is mainly due to the increased age of the building stock, and especially of existing residential buildings.

It is interesting to note that from the total of residential buildings, 2.5% was built before 1919, 5.0% in the period up to the 2nd World War (1919-1946), and 48.0% between 1961-80 (Hellenic Statistical Authority, n.d.). As a result, more than half of all the residential buildings in Greece (55%) have no thermal insulation, as they were constructed prior to the first Thermal Insulation Code (1981). Sadly, the 1981 Code was relatively recently (2010) replaced by KENAK, which is the adaptation of the EPBD (Energy Performance of Buildings Directive – 2002/91/EC) to the national legislation and further renewed with the standing code of 2017. The number of residential buildings constructed after 1980 is significantly smaller and is equal to 29.0% for 1981-2000 and 15.0% for 2001-2010 (Hellenic Statistical Authority, n.d.). After 2010, and due to the severe economic crisis that the country has been facing ever since, the construction of new buildings was significantly minimised.

The majority of the buildings in question (up to 1980) are built with the conventional construction system of reinforced concrete frame structure (U-value = 3.00 W/m².K, for 25-cm thick elements) with brick masonry infill walls (U-value = 1.30 W/m².K, for a double-leaf brick wall with a 5 cm air gap in between). The windows and doors are timber or aluminium, and have usually single glazing (U-value = 6.0 W/m².K).

Concerning the energy consumption characteristics of residential buildings in Greece, collected data show that (Energy Hub for All, 2017):

• Every Greek household has a total energy consumption of 13994 kWh/y.

• The mean annual energy consumption of heating energy (space heating, DHW, cooking, etc.) is 10244 kWh, with 85.9% pertaining to space heating.

Furthermore, space heating accounts for 63.7% of the total annual energy consumption, with 44.1% of the annual energy needs being covered with oil and 26.8% with electricity (Energy Hub for All, 2017).

Single-family houses are the most energy intensive, with a mean annual primary energy consumption of 358.7 kWh/m², in comparison to 241.6 kWh/m² consumed in multi-storeyed apartment buildings (polykatoikies). The mean annual energy consumption for heating is equal to 171.8 kWh/m². (Energy Hub for All, 2017) So, it is of great importance to explore means of reducing the conventional energy consumption for heating and cooling in single-family existing residences, especially within the current, grave economic situation.

Course description

The course of “Special Topics on Environmental and Bioclimatic Design” is a 6th-semester elective course that follows a building technology core course on bioclimatic design and aims to consolidate the acquired knowledge on sustainable environmental and climate responsive design, focusing on passive and low energy systems, by introducing the students
to thermal simulation analysis and parametric energy performance design. The selected simulation and modelling tool is the Design Builder® software.

The main purpose of the course is to familiarize students with the impact of small scale/minimal interventions to the thermal properties and energy performance of a building. While the key component variables (thermal insulation and relatively simple passive features) that are investigated in the paper are classical and small-scale, the study presents new potentials as it tries to attract students’ attention on existing and architecturally rather uninteresting buildings, which, nevertheless present a numerically important part of the existing building stock and in some cases may possess qualitative characteristics that may enhance their thermal performance. Moreover, the course tries to make the issues of the environmental crisis that are immediately linked to the built environment (conventional energy consumption for heating, cooling and ventilation, as well as preservation and upgrade of existing buildings and materials) an integral part of the architectural education process. Only then can the long-standing phenomenon of these issues being a “marginal issue in academic discourse” (Stasinopoulos, 2005) be overturned.

As a result, the educational goal is dual: firstly, to emphasise on the need to maintain and upgrade the existing building stock, irrelevant of its architectural and/or heritage values and secondly, to educate students on the necessity to assess simple passive design strategies, with a combination of quantitative and qualitative analysis of the basic environmental parameters (temperature, relative humidity, heat gains and losses, etc.). For this reason, the performance modelling of given, typical residences, namely given / conventional buildings was favoured over more complex architectural design projects.

Methodology

Description of the study

As mentioned in the previous section, the study is based on thermal simulation analyses with the use of the Design Builder® software. First, two typical single-storey houses were selected (Figure 1), one with a pitched and one with a flat roof. The selection was based on the fact that these two building types are representative and largely found in various parts of Greece. Even though the given building type appears in many variations, which also include two-storeyed buildings, the simplest possible forms were selected for educational purposes. The construction system and characteristics were the typical, conventional described in the previous section, namely reinforced concrete frame structure with brick infill and no thermal insulation. Additionally, heavy-weight construction with 60 cm-thick, stone masonry walls (U-value = 2,0 W/m².K), was also studied, as it is commonly found in suburban and rural areas around the country.

Figure 1. Models of the typical residences that were modelled, a. Single-floor, compact form with pitched roof and b. Single-floor, with semi-open space with flat roof.
**Parametric investigation**

The parameters that were investigated in the study are presented in Table 1. For various, appropriate combinations of these parameters, the following four scenarios were defined and simulated:

- **Scenario 0**: Base-case (as is)
- **Scenario 1**: Application of thermal insulation on walls, ground floor and roof and double-glazing to the windows.
- **Scenario 2**: Application of passive solar and/or passive cooling system(s).
  - 2.a Application of passive systems to the uninsulated house of Scenario 0.
  - 2.b Application of passive systems to the insulated house of Scenario 1.

The parametric investigation derived from the basic climatic characteristics of each climatic zone (A, B, C, and D) and the corresponding basic bioclimatic design principles. Inevitably, only cities with an available weather data file (.epw) were simulated.

<table>
<thead>
<tr>
<th>Table 1. Parameters investigated during the study.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Residence types</strong></td>
</tr>
<tr>
<td>1. Single-floor, compact form with pitched roof ✓</td>
</tr>
<tr>
<td>2. Single-floor, with semi-open space with flat roof</td>
</tr>
<tr>
<td><strong>B. Construction</strong></td>
</tr>
<tr>
<td>a. Conventional construction, no thermal insulation ✓</td>
</tr>
<tr>
<td>b. External thermal insulation ✓</td>
</tr>
<tr>
<td>c. Light-weight structure</td>
</tr>
<tr>
<td>d. Heavy-weight structure ✓</td>
</tr>
<tr>
<td><strong>C. Bioclimatic design</strong></td>
</tr>
<tr>
<td><strong>C.1 Passive Solar systems</strong></td>
</tr>
<tr>
<td>B.1.a Direct gain (south-facing openings) ✓</td>
</tr>
<tr>
<td>B.1.b Indirect gain</td>
</tr>
<tr>
<td>- Mass wall</td>
</tr>
<tr>
<td>- Trombe-Michel wall</td>
</tr>
<tr>
<td>- Sunspace</td>
</tr>
<tr>
<td>- Sunspace with opaque roof</td>
</tr>
<tr>
<td><strong>C.2 Passive cooling systems</strong></td>
</tr>
<tr>
<td>B.2.a Natural ventilation ✓</td>
</tr>
<tr>
<td>b. Night-time cooling</td>
</tr>
<tr>
<td>c. Shading ✓</td>
</tr>
<tr>
<td>d. Green roof</td>
</tr>
<tr>
<td>e. Evaporative cooling</td>
</tr>
<tr>
<td>f. Microclimate modification</td>
</tr>
<tr>
<td><strong>D. Climatic zones</strong></td>
</tr>
<tr>
<td>A – Southern Greece (Crete, Cyclades and south Peloponnese)</td>
</tr>
<tr>
<td>B – Central Greece ✓</td>
</tr>
<tr>
<td>C – Northern Greece (Epirus, Macedonia and Thrace) ✓</td>
</tr>
<tr>
<td>D – NW Greece</td>
</tr>
</tbody>
</table>

*Note: The tick sign ( ✓ ) denotes the parameters of the study that are included in the present paper (Section Presentation of the study / results).*

The students worked alone or in groups of two. The base-case models for each one of the two investigated building types were practically common to all the participating students. After that, each student, or group of students applied the selected strategies to the base-case model, according to the above-mentioned scenarios (Table 1). The number of simulated case studies was primarily based on the selected two residence types, whereas the different parameters depended on the number of students following the course. The main emphasis was on interventions on the building shell, mainly its thermos-physical properties, with the application of thermal insulation (conventional and external) being the
first and most common strategy, continuing with shading and followed by less “popular” strategies, such as solar spaces or Trombe-Michel walls. More drastic interventions, such as alterations to the window to wall ratio and advanced solutions, such as cool roofs and/or phase-change materials, which are discussed in relevant studies (Ascione, F., et al., 2016), were discussed in class, but omitted for reasons of simplicity and time limitations.

Assumptions

The main/primary goal of the project was to simulate the passive behaviour of the different models, before and after simple bioclimatic interventions. Consequently, a series of assumptions were made (Table 2), so as to minimise the various, defining parameters and to ensure that the achieved results are mostly due to the proposed interventions on the building shell. All the calculations were normalised by floor area, for the whole building (roof zone included) and the building without the roof zone (occupied zones only).

Table 2. Parameters investigated during the study.

<table>
<thead>
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<th>Tab</th>
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</tr>
<tr>
<td>HVAC:</td>
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<tr>
<td></td>
<td>Mech. ventilation / Heating / Cooling / DHW / Nat. Ventilation OFF</td>
</tr>
<tr>
<td></td>
<td>Nat. Ventilation ON (in the cases of summer passive cooling)</td>
</tr>
<tr>
<td>Activity:</td>
<td>Activity Template House</td>
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<tr>
<td></td>
<td>Different rooms templates: According to use</td>
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<tr>
<td></td>
<td>Computer / Office equipment OFF</td>
</tr>
</tbody>
</table>

Presentation of the study / Results

Due to the restricted size of the paper, only part of the overall research results will be presented. These are denoted with a tick sign in Table 1.

Heating period

The heating period calculations were generated from the ‘Heating Period’ tab, whereas the diurnal and seasonal variation of the various data were generated from the ‘Simulations’ tab. During the heating period, as was expected, losses are considerably reduced with the adding of thermal insulation.

The heat losses from the roof zone are considerable and comparable to those of the exterior walls. These result in increased heat losses from the rooms of the house, through the ceiling and towards the cold space under the roof. Thermal insulation of the ceiling slab practically reduces losses in half.

The uninsulated ground floor has a positive contribution to the winter thermal balance. This makes sense, given the fact that the ground has a significantly higher temperature than the air during the cold period of the year. Insulating the ground floor eliminates the compensation of this structural element on heat gains. If however, for some reason thermal insulation should be applied then the thickness of the material used should be carefully considered.
As far as the walls are concerned, both the conventional and the stone wall construction without insulation, have comparable thermal losses, with the former being somewhat worse (Figures 2 and 3), most probably due to its lower overall U-value. What is notable is the diurnal and inter-seasonal internal air temperature variation in the two different constructions that presents many similarities. (Figure 4) This is mainly due to the fact that the conventional construction is actually quite heavyweight due to the applied materials (dense reinforced concrete and double leafed brick walls). For the openings, the replacement of single glazing with double, offers a relatively small thermal losses reduction. Nevertheless, this fact is immediately related to the total glazing area of the building, and would be more pronounced if it were larger.
Figure 3. Heating period simulations. Diurnal temperature variation in the occupied zones of the different buildings (roof zone excluded) for the whole winter period for Athens (Zone B).
Finally, a set of calculations was done for the conventional and stone wall construction, without and with thermal insulation, for the main climatic zones (B-Athens & C-Thessaloniki) of the country. (Figure 5) As was expected, the prevailing lower environmental temperatures during the winter in the colder city (Thessaloniki) resulted in higher thermal losses, but the difference was significantly suppressed with the adding of thermal insulation.
The cumulative cooling period calculations were generated from the ‘Cooling Period’ tab, whereas the diurnal and seasonal variation of the various data was generated from the ‘Simulations’ tab. During the cooling period, as was expected and as was observed in the heating period calculations, fabric loads from the main parts of the building shell are considerably reduced with the adding of thermal insulation. (Figure 6)
significantly reduced when thermal insulation is applied. The walls and the openings in the buildings with no thermal insulation have considerable heat gains. Overall, though, as the glazing surface of the typical house under consideration is relatively small, the glazing has a significantly smaller effect on its heat balance. On the contrary, the large exterior wall surface has heat gains comparable to those of the roof, in the uninsulated models. The adding of thermal insulation in both types of construction (stone and conventional) reverses the wall gains, resulting in their positive contribution to the buildings’ heat balance. (Figure 6)

Figure 7. Cooling period – All summer. Diurnal temperature variation in the thick, stone-wall house (left) and in the conventional construction house (right) for the occupied zones (roof excluded) for Athens (Zone B).
For the summer period, the simulations show that simple actions, such as accurate natural ventilation (when the outside air temperature is below 27°C, combined with a high ventilation rate) and local, exterior shading of the windows results in notable changes of the interior air temperatures. The combination of both strategies, as expected, had a more pronounced effect on the interior air temperatures of the uninsulated, stone-wall house. It was also interesting to note that during the hot, summer period, the adding of thermal insulation on the exterior surface of thick, stone walls, reduced the diurnal temperature variation and the air temperatures in all occupied zones remained within or slightly above the thermal comfort boundary temperature of 27°C. (Figure 7)

In the conventional construction, thermal insulation improved thermal comfort conditions, as it lowered the maximum interior air temperatures. The combination of thermal insulation with natural ventilation and exterior shading had the most pronounced results, lowering interior air temperatures, during both the day and the night, and supressing their diurnal variation. (Figure 8)

During a hot summer day, the diurnal and heat flux and air temperature variation in the uninsulated variations of the two different constructions presents many similarities (Figure 9), due to the fact that they are both quite heavy-weight. This leads to various conclusions. Firstly, that for the summer period and for the southern parts of the country, where cooling period lasts longer and is characterised by higher outside air temperatures and intense solar radiation, it is better to use accurate ventilation and appropriate shading in stone buildings.
instead of applying thermal insulation. This may be the case in an increased number of summer / vacation houses that exist in the southern parts of Greece. On the contrary, the summer thermal behaviour of the conventional construction is significantly improved with the application of thermal insulation, and further enhanced with simple, passive cooling strategies.

Figure 9. Diurnal gains / losses and temperature variation in the occupied zones of the different buildings (roof zone excluded) for a typical summer week for Athens (Zone B).

Another outcome of the study, demonstrates a general observation related to the performance of ground floors (slabs on grade). As noted above, this structural element compensates notably in both heating and cooling periods. However, this effect is significant only in single-floor buildings with no basement. In these cases, the thickness of the thermal insulation layer of the ground floor slab should be carefully considered.
Finally, it was also interesting to note the pronounced effect of the unoccupied roof zone on the heat flux and air temperature variation of all the variations. Even in the case were the slab separating the roof from the house is insulated, the roof still significantly affects thermal comfort conditions in the occupied areas of the house, contributing to the house overheating during the day and its significant cooling during the night.

Conclusion

The results of the study are two-fold and involve on the one hand, the assessment of simple bioclimatic interventions to existing buildings’ energy performance and thermal comfort conditions, and on the other, the teaching outcome of the course.

Concerning the results of the study, it is clear that simple bioclimatic interventions to existing buildings can significantly lower conventional energy consumption and improve thermal comfort conditions. Furthermore, it is worth noting that half of these low impact interventions that basically refer to the building envelope, do not interfere with the users’ activities and compensation and thus may demonstrate a significant improvement on the building thermal performance and energy use, especially due to the geometry of the building.

In relation to the teaching outcome of the course, similar to previous research (Delbin, et al., 2006), it was clear that as building simulation tools are not fully adapted to standard design studio practice, the students take up considerable time to learn how to use the simulation software, and especially how to set up the model layout and configuration. As a result, it was proved difficult to run all the necessary simulations and reach qualitative and synthetic conclusions, within the time constraint of the regular 13-week semester. Moreover, it is clear that students at this level, given their small experience on such matters, have not yet developed the necessary criteria and knowledge to exploit all of the software’s possibilities and always conclude to accurate observations.

Acknowledgements

The authors would like to thank the students: A.Athanasiou, S.Chliaoutakis, G.Drabalou, E.Kanaraki, M.Kofaki, G.Meletis, A.Ninou, R.Skarmalioraki, L.Slibi, V.Soldatos, D.Timagenis, M.Tsagkareli and G.Zitouni-Petrogianni, that participated in the course in the academic year 2016-17, and on whose semester work this study is based.

References


Design Builder® Software, v.5.3.0.014, software program, © Design Builder Software, Ltd.
RESILIENCE OF MEGA PROJECTS: A STUDY OF SOCIAL RESILIENCE IN LOMBOK INTERNATIONAL AIRPORT SURROUNDING AREA

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Abstract: Development of Lombok International Airport has resulted a transformation not only in the land use of Lingkar Bandara (area surrounding the airport), but also the livelihood of the villagers who live there. Located in agricultural land whereas the main occupation of local population are mostly farmers, the airport has brought service-based industry occupation which the local population need to adapt to. While development of the airport has brought positive economic growth, and infrastructure development, the transformation also generates friction and conflict of interests between stakeholders. Therefore, while development focuses more on economic and spatial planning, this study will assess social resilience against gentrification which is the ability to cope, adapt, and build positive transformation from the development of the Lombok International Airport. From the study, author finds out that the level of social resilience of Lingkar Bandara community are quite low. The conclusion was based from data collection from field works which fulfil social resilience three categories: coping capacity, adaptive capacity, and transformative capacity. Although the level to cope with the development is quite high by maximizing their informal network, the community level of awareness, and preparedness towards the possibility of gentrification is really low. Furthermore, high level of adaptation of local community results in disturbance to airport’s development and operation. Lastly, low level of building a positive development is low due lack of participation and communication between stakeholders which would jeopardize long-term economic gain from the airport development.

Keywords: Social resilience, sustainable development, rural development, mega project, airport development

Introduction

Lombok International Airport is a new airport that starts operating in 2012 in Lombok Tengah, Nusa Tenggara Barat. The airport was built to replace Selaparang airport that is located in Mataram city. Due to increasing passengers, and limited space to further develop Selaparang airport, Lombok International Airport was built one hour away by drive from Mataram City in the province of Lombok Tengah. Other than becoming the gate for the region for domestic and international passengers, the airports have another role as a growth pole for the surrounding region.

The development of Lombok International Airport has resulted positive benefit to Lombok Tengah region. According to a research by Hartanto (2015), the development of Lombok International Airport has resulted an increase in land value. However, proximity to the airport have pulled private investors to develop hotels, restaurants, gated communities, and various small businesses. It is likely that this development trend will continue to rise with large areas of the agricultural land have been bought by investors and planned for construction. With the amount of urbanization taking place on the area, social resilience of local community that lives surrounding the area are still lacking. With the amount of employment growth in service-based industry, local population need to change their livelihood from working in agricultural business. With higher land price, and incoming investors to take benefit of airport proximity, local population have risk of gentrification. In this case, the definition of gentrification came from Hamnet (1991), who argues that gentrification is the replacement of working class by middle or upper class income. By putting

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this understanding into the context of rural development, it is safe to say the term gentrification as middle-class group replacing another lower income people due to shifting land values (Zuk et al, 2015).

While there are already many studies of airports in the context of cities, research of airport located in rural areas/ green field area is lacking. With many potential of development for the surrounding area, integration with the surrounding population is key to build resilient and sustainable development. Thus this research will focus on the social resilience of local population towards urbanization from the development of Lombok International Airport.

**Social Resilience**

The first inception of resilience is introduced by Holling (1973), quoted “the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist” (Holling, 1973). He then changed the definition of resilience as the ability to maintain ecosystem from changes and stay in its equilibrium state (Holling, 1996). Equilibrium in this matter is maintaining the same social structure, function and identity while facing disturbance, threats, or external factors. Holling (1996) also mentioned that the system not only be able return to its original state, but there is possibility for the system to improve, adapt and transform. The higher the level of social resilience of population means the bigger the size of disturbance it could absorb before it becomes stable again. On the other hand, a low level of social resilience would get less benefit from economic growth and instead have a risk of increasing inequality compared to communities with higher resilience.

Thus brings us to the questions “resilience of what to what?” (Folke et al, 2010). While in social resilience is mostly used to identify ecological science, disturbance is usually known as natural disaster which occur in a short period of time but a very high intensity. Hill (2015) later argues that disturbance could also come in a long period of time, and change gradually. The state of disturbance would later become unseen, as ’a boiling frog’. Folke et al. (2010) suggested that the increasing rate of human population and activities also have become a global issue. Top-down approach, policy changing, urbanization, rural migration, discrimination, poverty, climate change, new infrastructure, or change of leadership could startle the already moving equilibrium and have a subsequent impact on the livelihood of the population and societal development (Folke, 2006).

**Component of social resilience**

Keck and Sakdapolrak (2013) suggested that the study of social resilience can be used as a theory which able to relate the concept of vulnerability and can be used in today’s challenges of uncertainty. He continues that social resilience can be divided into three different capacities (Béné et al, 2012): *Coping capacity* – the ability to absorb disturbance and avoid long term negative impact, *adaptive capacity* – the ability to grasp the changing situation and make alternative choices, and *transformative capacity* – the ability to make a positive impact out of the changing situation (see Table 1).

**Coping capacity**

Coping capacity is the embodiment of the term resilience that have earlier been discussed by Holling (1973), in which the ecological system absorbs change and disturbance and return back to its original state. Keck and Sakdalporak (2013) suggested that one of key quotes to define coping capacities is restoration using resources that are directly available. Hill (2015) divided coping capacity to three components; informal networks, infrastructure accessibility,
and food insecurities. The theory goes in parallel with Frankenberger et al. (2013), who suggests that coping capacity is highly affected by local inhabitant’s assets which includes, human capital, natural capital, social capital, financial capital, physical capital, and political capital. Thus, author concludes based on previous scholar framework and most compatible aspect of coping capacity with the case study. Aspects that effect coping capacity includes:

Livelihood assets – Livelihood assets are tangible and intangible material that help the basic needs of community and population. It consists of human capital, natural capital, financial capital, political capital, social capital, physical capital (Frankenberger et al, 2013; Hill, 2015). Livelihood between urban areas and rural areas are considerably different. For example, natural capital in urban areas are not as significant as in rural areas where the main occupation is in agricultural products. The term livelihood and resilience are related between each other closely (Hill, 2015; Pain et al, 2012). Lack of livelihood assets makes the community more vulnerable with future shocks or disturbance. While livelihood consists of both social capital and physical capital, author divide the two aspects to have better understanding.

Informal networks/ social capital – this component has a very strong influence towards the level of resilience. Social capital determines the relation of the community and neighborhood by embedding norms, moral codes, and trust between individuals or community (Frankenberger et al, 2013), Research by Aldrich (2012) could be useful to assess social capital community which identify social capital into 3 categories: bonding social capital, bridging social capital, and linking social capital.

Infrastructure accessibility – physical capital. This section will refer back to previous understanding of infrastructure. Infrastructure divided into hard/physical infrastructure, which includes roads, railways, utilities, and service that connects commercial, industrial, residential services. While social infrastructure defined as housing, education, health and support services (Keast et al, 2008).

Adaptive capacity
After coping capacity have been fulfilled, community will move on to adaptive capacity. While coping capacity is the process of getting back to original state, ‘humans in nature’ might be able to learn from past experience to newly adapt to global environment change (Keck and Sakdapolrak, 2013), and anticipate future disturbances (Hill, 2015). Adaptive capacity allow local inhabitant to adjust their livelihood to disturbances, while also changing and securing their present status (Keck and Sakdapolrak, 2013). According to Hill (2015), adaptive capacity components involve in social awareness and initial strategy of the community to perceive future disturbance. The ability to perceive future disturbance would allow them to prepare, adapt, and reduce the possibility to get affected by shocks and risks. However, author also inserted theory from Keck and Sakdapolrak (2013) that mentioned about using past experience as a tool to enhance adaptive capacity. The theory goes in parallel with Frankenberger et al. (2013) theory which suggested that memory enables new understanding, shorter duration for adaptation and response. Furthermore, Frankenberger et al. (2013) suggested that increasing awareness would need high level of bridging social capital, and linking social capital as it would gain local inhabitant broader knowledge. Thus, adaptive capacity consists of:

Ability to anticipate future disturbance (awareness) – preparedness and ability to access information within the community and outside of community. The ability to perceive future threat and risks allow the community to consider their capitals, and necessary action for individual or community level. Awareness of future threat becomes an important aspect that would highly affect the other two aspects.
Community adaptation – Learning and Innovation is key to challenge community and individual towards future threat. This component is a significant process for coping, adaptive and transformative capacity. It is the ability and willingness to taking risks for new opportunities, creating new knowledge and modifications based on past experience (Frankenberger et al, 2013). Community adaptation involves the changes that the community is willing to take for the well-being of their livelihood. However, community adaptation is different than individual adaptation, and to add more complexity. Individual adaptation could become a barrier for adaptation for another individual.

Initial Response to threat – Self Organization within individual level, and community level is related to human capital, social capital and political capital in coping capacity. It is based on the closeness of between individuals, individuals with community, community with local municipalities, and so on. Higher level of self-organization determines community plan, and organize to future threat. Frankenberger et al. (2013) suggested another dimension called preparedness. Preparedness is the way community perceive awareness and take measures by directing their resources as well as attitudes towards the disturbance.

Aspirations – Aspirations defined as objectives and goals which the community be willing to attain or realize (Kosec et al, 2014). Aspirations help community to vision themselves in distant future, and able to act upon the vision. With many negative memory of government development, community need to hold a positive aspiration in order to develop the community further. Aspirations is affected by cultural, norm, and local structures (Frankenberger et al, 2013).

Transformative capacity
While coping capacity is the state to maintain its original state, and adaptive capacity enables the community to adapt to future disturbance, Transformative capacity enables community to enhance large scale changes and development (Keck and Sakdapolrak, 2015). Holling (1996) stated that it is possible for an equilibrium to reach a new variable state. However, to do so would need a change in the system not only in the community but also all actors and stakeholders that could benefit for development. Béné et al. (2012) later argues that the transformation to new state could also means disappearance of others, e.g. agricultural culture which is gone transformed into fully industry based region. O’Brien (2011) suggested that the transformation could be in different components of society. Transformation could be within social structure, occupation, technological innovation, identity, fixed beliefs, or institutional reformation. According to Frankenberger et al. (2013) transformative capacity would need a high level of both bridging social capital and linking social capital, while also having an active role from local municipal and power-holder to build beneficial policies. The theory has resemblance with dimensions of transformative capacity from Hill (2015) which consists of:

Level of participation – participation is key for larger scale transformation. Participation between locals with government programs, participation within the community itself is key. The ability of absorbing and transforming disturbance into positive transformation as Keck and Sakdapolrak (2013) argues, “involve different societal factors that both facilitate and constrain people’s abilities to access assets, or gain capabilities for learning, and become part of decision-making process.” There are already a lot of research about participatory planning in the context of urban planning (Arnstein, 2004; Gaventa, 2006) and concluded that participatory bring positive to development by sharing power relation.

Level of social inequality – Large scale transformation needs the analysis of all structural and relation that contribute to development. The issue needs to cover all aspects of
community, rich or poor, race, all castes, ethnic group nor gender. Keck and Sakdapolrak (2015) argues that we need to understand place of unequal distribution whether for vulnerabilities, or potentials to deal with disturbance. Higher gap of social inequality would likely separate and weakens community resilient against future disturbance.

Communication – communication is the basic fundamental for participation. Communication needs to be maintain from individual level - community level - regional level – national level and global level. The higher level of communication enables higher degree of knowledge, freedom of choice, and collective decision.

<table>
<thead>
<tr>
<th>Table 1: Component of Social Resilience</th>
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<tbody>
<tr>
<td>Coping Capacity</td>
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<tr>
<td>Social Resilience Components</td>
</tr>
<tr>
<td>Livelihood Assets</td>
</tr>
<tr>
<td>Informal Network</td>
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<tr>
<td>Infrastructure</td>
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<tr>
<td>Accessibility</td>
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</table>

Social resilience is a relatively new theory, thus finding studies of the implementation of the theory is a challenge. Thus author took the most resemblance social resilience component by Hill (2015) which have similarity with different scholars such as Frankenberger et al. (2013) and Béné et al. (2012). However, there are different parameters which makes this study different. First, while research by Hill (2015) is to assess social resilience against urbanization, this research involves another stakeholder, which is airport and development surrounding the airport. The airport as stated in the beginning of this chapter brought infrastructures, increase employment, and economic growth, which will affect level of social resilience of local inhabitant. Social resilience is a dynamic theory which evolves and changes every time. The results also may differ from individual, regional and nation level.

LOMBOK INTERNATIONAL AIRPORT AND LINGKAR BANDARA

Lombok International Airport is a new operational airport located in Praya region, Central Lombok, Lombok island. The airport that begins operation in 2012 lies on more or less 500ha of agricultural land that have been bought in 1995. The location of the airport is 40km away from the capital city Mataram, and connected by main artery road, Jl. Bypass Bandara International Lombok. The airport was built to replace Selaparang airport that is located in Mataram City and located near three villages: Desa Tanak Awu, Desa Ketara which is located in Pujut district, and Desa Penujak which is located in Praya Barat region. The three villages which located in the radius of 5 km from the airport entrance are the villages that are going to be the focus of social resilience assessment by the authors and called by government and airport officials as Lingkar Bandara, as seen in the map of case study in Figure 1.

Lingkar Bandara region mainly consists of agricultural land with the size of 233.55sqm. Main livelihood of local population based on farming with the highest occupation of 26,86%. Total population of each village are approximately around 2500 households. Before the development of the airport, there were no electricity and no asphalt road. Houses are mainly made of bricks, and numerous are still made of bamboo seen in Figure 2. Due to the proximity between the three villages, local population mainly are relatives, making their social integrity strong. Known as “island of 1000 mosques”, Lingkar Bandara region also equip mosques nearby village administration office. Mosques, and village administration office become the
center of the community to discuss issues and problems in the villages. Every village is led by village leader which are pointed through voting and democracy.

With the development of Lombok International Airport, the surrounding area has transformed. According to research by Hartanto (2015), the land value surrounding the airport as well as near the main artery road have significantly increased. Economic growth has gradually increased from 6.19% to 6.25%. This economic growth has been supported by hotels and restaurants which started to emerge at main Artery road. Within the radius of 5km from the airport, there are more or less 4 hotels that are privately owned. Other than hotels and restaurants, local residents also start to build flats to accommodate employees of the airport that comes from outer regions. Development of resident have vastly increased in demands due to development of Lombok International Airport. Near the airport two new residential areas have been constructed. These are gated communities with 30-40 houses which most are not occupied yet.

**RESEARCH METHODOLOGY**

The research focused on qualitative approach as well as thorough research on the background and statistic of the case study. Author chooses to do qualitative research to obtain in-depth data on the experience of each individual as well as community in a whole towards the development and how they adapt to the situation. By using qualitative research, we could
also obtain the correlation between social resilience capacities and how each factor determined another one.

To collect the data, author have conducted several interviews which consist of different groups. The first group is airport officials which consists of airport officials (head of departments), Second group is the airport employees which consists of four employees that works inside the airport, one focus group which consists of four people, and an additional employee that works at the shop in the airport region. The third group is Lingkar Bandara population which consists of four entrepreneurs, four farmers, three public servants/farmers, and two village leader. Lastly, author have interviewed also an expert from the government who had previously research of the case study.

For the interview itself, author preferred to have semi-structure interview than a structured interview. Reason being, the author wanted the interviewer to tell their experiences and livelihood, with semi-structured interviews, the interviewer could emphasize on a certain point of interest to discuss. It also enables interviewers to speak more widely on the issues they chose. As guidance of the interviews, authors develop questions based on the parameter of social resilience theory. Author used mobile phone as a recorder, and taken discreetly. This methodology is important while some of local inhabitants still didn’t want to open up to outsiders due to previous conflict between the airport and Lingkar Bandara. However, author explained that the interview will be used in scientific research at the end of the interview. Most of the interview didn’t last longer than an hour although doesn’t limit the possibility to have a longer duration to gain more in-depth perception from the interviewer.

After all the interviews had been gathered, due to different language, author have translated all the key quotes. All key quotes have been labelled and coded accordingly so readers can easily search. By obtaining this direct information will be important to get first-hand experience of local people who got affected the most by the development of the airport. Lastly, author will also combine data analysis with photos taken from internet, and photos taken from author’s field visit to Lombok.

**SUMMARY OF KEY RESULTS**

In the context of Lombok International Airport, social resilience of Lingkar Bandara assessment are differed in level on coping capacity, adaptive capacity and transformative capacity. The results are as follows:

**Coping capacity**

From the interview, Lingkar Bandara informal network is quite high between the villagers. This is because the population share the same ancestor and closely related between each other. furthermore, the villagers often spend time together through religious activities as seen in Figure 3. Moreover, Lingkar Bandara community’s network is also quite high. This can be seen from the ability of the villagers to work outside the region, as well as worker in middle east. However, network between the villagers with government and airport officials is very low.
Lombok International Airport has brought along several infrastructures that are implemented in the Lingkar Bandara region. One of the biggest improvements is road infrastructure which connects the airport to several tourist destination and the capital city Mataram. Furthermore, water and infrastructure have become a standard, and almost everyone already have access to the infrastructure. Water infrastructure is relatively easy to get, despite not all villages are supported by Pelayanan Air Minum (PAM). Most of the villagers uses groundwater as their main water source for daily needs and sometimes for agricultural need. Electricity have been significantly improved while electricity source for the airport can also be used by the villagers.

With 80% of the region covered with agricultural land, the livelihood of Lingkar Bandara villagers are mainly supported by farming products. The lands are mostly a heritage from each land-owner’s families and been passed down for generations. With a strong bonding social capital, sharing lands and houses between families are a common practice. Villagers live in a small clusters of big family, in which if there are extra land, can be used to support their families who are in need. Thus, livelihood of individuals is affected highly by their bonding social capital as it secures them a place to live when facing threat of gentrification or displacement. In additional, high level of bonding social capital also helps individual resilience because every family not only will share lands but also food.

**Adaptive capacity**

From the interview, villager’s anticipation of future risk and disturbances are quite low while the disturbances of gentrification come gradually and hard to predict. Some farmers realize that there is no more future in agricultural and farming, thus enable them to build preparation for future development. On the other hand, from the interview and samples that author have done, most of the samples aware of future disturbance, in a sense that the development would give instead positive changes, and boost economic growth. Only a few samples realize that with many newcomers with higher education, and capital from outside the region, it could be the start of gentrification where Lingkar Bandara population will be replaced by middle-income people due to incapability to compete.

The level of adaptation can be seen by the ability of each individual to adapt in their own term, by experimenting, making innovation, and exploitation of new opportunities that they have found (Béné et al, 2012). With the development of Lombok International Airport, some ‘new’ occupation and opportunities have emerged to catch the ‘wave of development’. For example, the role of informal taxis to fill in the gap of public transportation has emerged.
Other than informal taxis, the villagers also sell goods near the terminal, opening hawkers and food stall outside of the terminal seen in Figure 4. These innovations are what Lingkar Bandara inhabitants sees as an opportunity for short-term capital.

While adaptation is about changing livelihood, initial response to threat is to analyse preparation from the villagers in facing disturbance. Preparations for disturbance are highly emphasized by the amount of assets a family have. While some individuals may see development as a threat, adaptation could also mean an opportunity for someone else. Family with lower capital have limitation to fund their aspirations for a better future, thus they resort to do different kind of job and willing to work oversees to keep their family future well being. On the other hand, family with higher capital would prepare their assets to purchase and invests on lands around the airport. While initial response of each individual may differ from each other, level of preparation in the scale of community are highly affected by the role of village leaders.

![Figure 4: (from left to right) villagers selling goods inside terminal building, villagers selling food inside airport area. Source: http://assets-a2.kompasiana.com/ ... accessed 15/08/2016).](image)

In the context of Lingkar Bandara community, aspirations of each individual are quite similar to each other. Other than their high level of aspirations to keep their children educated, and to keep their livelihood, author finds that their willingness to keep their ancestor land is quite high. These strong aspirations to keep their land for future investment creates a high level of social resilience.

**Transformative capacity**

The level of participation between the villagers with airport have different issues and challenges. While level of participation in the first years is quite high by having close relationship with local leaders. However, the operation and development of the airport itself have become slower due to high demands from the local community to gain wealth. The lack of participation makes the villagers to feel secluded from the development, which raised the tension between airport officials and Lingkar Bandara community. Despite the fact, there are numerous strategies from Lombok International Airport to increase the participation in operating. After suggestion and recommendation, airport facilitate local hawkers by building local shops within airport area. With the same methodology, airport employees have planned to formalized informal infrastructures, by making partnership between the airport and informal taxi drivers.

Author finds that the level of social inequality is quite high in Lingkar Bandara region. A few factors that affect social inequality is their strong bonding social capital due to blood
relation from one to another. Strong bonding social capital and sharing assets between individual produce sense of equality in Lingkar Bandara community. The connection between families who have higher capitals, and lower capitals are very close, and give mutual benefit in the process of farming. Rather than having a vertical relation where land-owners become the employer of farmers, author finds the relation is more horizontal. Sometimes, land-owners also assist other families in harvesting season. However, with the new development of Lombok International Airport. The dynamic changes of socio-culture to adapt to the new environment and development have opened certain opportunities that is not distributed equally.

Author finds that there is a misinterpretation of the airport program that are done to break communication barrier between the airport and Lingkar Bandara. While CSR programmes contributes to local community by donation of money, irrigation pump, and mobile clinic, communication is perceived differently by Lingkar Bandara community. Lingkar Bandara community believes that airport officials need to keep Silaturahim which is already embedded in Islamic culture. By occasionaly visit one another, or holding event together would increase bonding social capital which will break the barrier between stakeholders.

CONCLUSION

From the interviews and data gathered from field work, author concluded that the level of social resilience is low. Low level of social resilience proved that local population couldn’t adapt to the development of the airport and the transformation of livelihood from agricultural to service-based industry. Furthermore, the study shows that the level of social resilience of local population would disturb daily operational of the airport. This results in conflicts between stakeholders which would jeopardize the sustainability of further development.

Policy and guidelines need to focus not only in the development of hard infrastructure, but also in parallel with soft infrastructure. By analyzing social resilience of local population, decision maker and urban planner have to build a holistic design which would benefit local population at the surrounding of mega project such as Lombok International Airport. Despite the fact, there are many gaps that needs to be filled to increase the knowledge of social resilience as well as mega projects.

Informal economic activities are an increasing factor in economic growth in developing countries (Quintin, 2017). By focusing on transformative capacity, research in participatory planning and integrate them to policy and guidelines can become a strong tool for decision makers to build a sustainable development.

Social resilience is a dynamic theory which could change by time. While informal network of rural communities are high, the influence from newcomers and inclusion become an important factor that could affect coping capacity. Further research on the affect of the development towards closely related rural community is an interesting subject.

Social resilience is a relatively new theory to observe dynamic social behavior of local inhabitants toward man-made development. Research for improving social resilience theory as a tool for planning and decision-making and its relation with sustainable theory is a sparrowing perspective to research.
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Urban Regeneration to Reclaim Sustainability in Cities: The Case of Down Town Riyadh, KSA

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Abstract: As a result of rapid urbanization in developing countries over the past 20 years, cities have experienced massive growth beyond their traditional downtowns. In the case of the Saudi capital Riyadh, the expansion of the city and the emerging of new modern centres had caused the central downtown to lose its former role and to fall into a state of decline. In 2013 a new plan was introduced for a regeneration project in this area, with the goal of its revival and transformation into a national, historical, administrative and cultural centre. In order to understand this plan in terms of its contribution to sustainability, this research conducted an analysis based on the application of sustainability indicators from the International Sustainable Building Tool for Urban Planning. Results of the study demonstrated how plans were successful in accounting for most sustainability indicators. However, few essential issues were not considered and were highlighted as well. The study showed the significance of sustainability indicators as a methodology and how they can be an effective tool for driving successful science-based urban planning to inform decision making processes in a city.

Keywords: Sustainable development, urban regeneration, Sustainability indicators, Riyadh City.

Introduction

Many cities across the world are experiencing extraordinary growth and Riyadh is one of the fastest growing cities in the Middle East. The city, with a population of less than 15,000 people at the turn of the last century, now has a population of about four million people and it is projected to expand to about 8 million by the year 2030 (UN HABITAT, 2016). As the city continued to grow, its functions continued to change as well. This change was not necessarily positive, as it had caused older areas within the city fabric to lose their attractiveness and competitiveness. One clear example is the city down town area.

Historically, Riyadh central area formed the heart of the city with the seat of government and the main mosque in addition to a vibrant commercial centre that was severing the entire region. Recently however, the area has been going through fast decline and no longer functions as the down town for the city. Recognizing this, local authorities are seeking to develop the area in order to retain its former glory and better integrate it within the city. For this purpose, a regeneration plan has been proposed with the goal of creating a livable, vibrant, and sustainable city center. Hence, within this development framework, the research is highlighting the issue of sustainability in the built environment.
It is believed that cities will give answers to a sustainable future, since they are the largest resources consumers of the planet and the largest generators of waste, but cities are also the place where it is possible to act more effectively to save the planet (Castanheira, 2014). So eventually, the question of sustainability cannot be overlooked when discussing urban development in today's cities.

In this regard, urban regeneration is considered as one of the fundamental mechanisms for achieving sustainable urban development. It contributes towards sustainability through the ‘recycling’ of land and buildings, reducing demolition waste and new construction materials, as well as reducing urban sprawl, and facilitating compactness of existing urban areas (Turcu, 2012).

Urban regeneration is mainly targeting the improvement of city centres, former industrial areas, and housing areas facing decline due to intersecting pressures. Typically, urban regeneration actions involve economic, social and physical improvement measures. In this sense, sustainable urban regeneration is understood as regeneration actions, policies and processes within a city, which address interrelated technical, spatial and socio-economic problems in order to reduce environmental impact, mitigate environmental risk, and improve environmental quality of urban systems (Czischke et al, 2015).

Hence, with the aim of supporting decision-making in urban regeneration, this paper proposed an indicator-based approach for the assessment of downtown regeneration plans in Riyadh city. The goal is to find out how principles of sustainable development are being considered in the future plans and how these plans are contributing to the enhancement of the urban environment in the area.

Theoretical Background

**Study Area; Riyadh Down Town (Central Area)**

The Central Area covers around 1,500 hectares and is the traditional heart of Riyadh, but its current development character does not reflect the importance of the Central Area to the city as the area has seen many changes over time. In the past it was an area where Saudi locals lived in a traditional, low density, ‘human’ environment with the area being recognized as the Kingdom’s Seat of Government. More recently however, it has become an area dominated by problems and inhabited mainly by low income, non-Saudi expatriates (80% of the residents). The character has changed, as has its physical condition, neglect and decay is apparent in many parts (ATKINS, 2012).
As a result of decline, a number of key challenges have been identified that face the Central Area and its long term future, including; Deterioration of a number of valuable historic buildings, Lack of services and public facilities, High traffic density, a lack of sufficient parking and pedestrian walkways, and deteriorating social conditions including high levels of criminal activity (ATKINS, 2012).

To address such issues, as well as respond to the overall vision for the City as set out within The Metropolitan Development Strategy (MEDSTAR), the Arriyadh Development Authority (ADA) has set out to establish a Visionary Concept Plan and high level Implementation Framework capable of guiding future work on the regeneration of the historic centre of Arriyadh (ATKINS, 2013). The plan objectives include conservation of urban and cultural heritage, preservation of the existing commercial activities, creation of more employment opportunities, diversification of housing patterns, achievement of social and demographic balance, and consolidation of urban security, as well as improvement of the area’s road network and public utilities (Arriyadh Development Authority, 2015).

Sustainability Indicators

In recent years, assessment tools with various indicators have been developed and applied in different contexts to determine the level of sustainability in cities. They work as a guide to help cities and urban areas in the achievement of more sustainable developments. Such tools include; Building Research Establishment’s Environmental Assessment Method (BREEAM), Sustainable Building Tool (SBTool), and Leadership in Energy and Environmental Design (LEED) (Braganc et al., 2010). They form the basis for the other approaches used throughout the world and are usually based on several indicators to be evaluated according to different categories related to design and construction features of buildings and neighborhoods, resulting in a score or rating for sustainability.
As cities and organizations are focusing on the development of indicators to measure progress, it can be stated that such indicators should closely be associated with the main objectives of sustainable development where they can be used to assess the achievement of a city or a community providing both quantitative and qualitative data (Marzukhi et al, 2011). In this sense, indicators are able to assist urban planners, local authorities and other key stakeholders to support an analysis of new developments, as well as of existing districts, from an environmental, social and economic point of view.

A vast number of indicators have already been developed and suggested worldwide. Therefore, it is possible to adopt indicators and indicator sets from already existing international or national approaches to the assessment of sustainability in cities and districts. However, Special attention should be paid to the examination of data availability and the selection of information sources (Lützkendorfa & Balouktsia 2017). In the upcoming section, the indicators adapted for this study are going to be viewed along with their scope.

**Research Framework**

Empirically, there are few studies which focus on single developments and their performance against specific assessment tools. Hence, it is essential to address this issue with more investigation in different contexts. In the case of urban districts, the assessment can aid in the identification of problem areas, the development of strategies for improvement and the ongoing monitoring of the success and impact of the adopted sustainability interventions and measures (Lützkendorfa & Balouktsia 2017).
This study investigates sustainability within the proposed regeneration plan for downtown central area of the Saudi capital Riyadh. The assessment methodology adapted a number of indicators from the Sustainable Building tool for urban planning (SBTool- UP) which is used for assessing the sustainability of the built environment, particularly, urban planning and urban regeneration projects.

The SBTool- UP is based on the international Sustainable Building tool designed for the assessment of buildings and was developed by the Laboratory of Building Physics and Construction Technology in the University of Minho, Portugal. It was also utilized in the assessment of several regeneration projects across Europe and it has proved its usefulness regarding the evaluation and comparison of developments to determine best practices in sustainable urban regeneration (Castanheira et al, 2013).

It is important to point to the fact that a large number of studies have been conducted in terms of regeneration impacts with the focus on one certain aspect of impacts, like social or economic. Hence, this study is taking a more comprehensive approach addressing environmental, social, and economic factors which is indicated in the choice of indicators to be analyzed. According to data availability, 17 indicators have been selected from the 40 indicators outlined in the SBtool- UP. They present the three dimensions of sustainability as follows; 6 from the Environment category, 8 from the Social category, 2 from the economy category.

To assess the presence of these indicators in the proposed regeneration master plan, a content analysis was conducted including a systematic reading of the proposal text, figures, tables, and maps provided by Arriyadh Development Authority and the consultant firm ATKINS.

Results of the analysis are presented in tables 1,2,3 comparing performance between the existing situation and the future plan against the selected indicators. The comparison was conducted to help identify current conditions within the study area, highlighting proposed improvements and allowing for a more comprehensive understanding of the area under study.

**Analysis & Results**

The goal of the study was to evaluate the regeneration plans for Riyadh down town central area against sustainability indicators adapted from the international SBtool for urban planning. According to these indicators, a comparison between the current situation of the area and a future scenario based on a comprehensive development plan was conducted to investigate the proposed enhancements and how they can contribute to the creation of a sustainable environment.
<table>
<thead>
<tr>
<th>Categories and Infrastructure</th>
<th>Indicators</th>
<th>Parameter</th>
<th>Current area situation</th>
<th>Proposed Scenario</th>
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</thead>
<tbody>
<tr>
<td>Density &amp; flexibility of uses</td>
<td>Percentage of areas with flexibility of uses</td>
<td>The area has historically been a focus for trade with large number of souks serving the region, they are clustered in two main areas of Al Muraba’ area and Batha’ street. Distribution of Land uses; Residential= 31%, Commercial/entertainment=6%, Government= 4%, Empty land= 6%</td>
<td>Commercial role remains the same with enhancement to the deteriorated areas. mixed use corridors are identified along main streets. 18 special nodes are to be developed with mixed uses and two of them as TOD areas. Distribution of Land uses; Residential= 22%, Commercial/entertainment=10%, Government= 8%, Empty land= 0%</td>
<td></td>
</tr>
<tr>
<td>Built environment rehabilitation</td>
<td>Percentage of existing structures rehabilitated and reused</td>
<td>The area contains a large number of important historic buildings Including: Al Murraba Palace, Mismak Fort, The traditional mud brick houses in Al Duhaia area, and Modern Heritage including Barkiyah Radio Mast, and the water tower.</td>
<td>The regeneration project vision is to conserve and restore valuable historic buildings to be given new adaptive uses as cultural centers. percentages of such buildings to be reused are not specified.</td>
<td></td>
</tr>
<tr>
<td>Distribution of green spaces</td>
<td>Percentage of green spaces</td>
<td>parks form 5% of land use and are located mainly in King Abdul-Aziz cultural center and Salam Park.</td>
<td>Parks are increase to 10% of land use forming a hierarchy of; District Parks, Local Parks, and Pocket Parks. Also several green boulevards are proposed along main streets.</td>
<td></td>
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<tr>
<td>Renewable energy</td>
<td>Percentage of consumed energy from renewable energy produced on site</td>
<td>Electricity generation for central area and Riyadh as a whole is largely sourced from gas fired power stations.</td>
<td>Enhancing energy production includes the king Abdullah City for Atomic and Renewable Energy program to develop renewable and nuclear energy, however the projects is still in early stages.</td>
<td></td>
</tr>
<tr>
<td>Consumption of drinking water</td>
<td>Index of water reuse</td>
<td>There are no Sewerage Treatment Plants (STP) and no reticulated a Reuse Quality Treated Sewage Effluent (RQTSE) in the area. Two pump stations and Reverse Osmosis (RO) plants on King Fahad Road allow the treatment and utilization of ground water collected from that line. Part is used to irrigate the King Fahad Road landscape, Salam Park, and King Abdulaziz Historical Centre.</td>
<td>It is proposed that a RQTSE network be constructed from the Riyadh STP to supply water to irrigation reservoirs in the Central Area. Treated drainage water could also be fed into the reservoirs, where water could then be pumped via a network to irrigate the public realm. Surplus water from the King Fahad Road treatment system may also be directed back into the Central Area.</td>
<td></td>
</tr>
<tr>
<td>Management of wastewater</td>
<td>Percentage of permeable area</td>
<td>Most of the area, is currently hard surfacing, with relatively high runoff co-efficient. A storm water reticulation network covers most of the district. There are many streets where this network does not reach. Permeable areas form about 10% of central area.</td>
<td>The plan proposes increased areas for parks and open spaces, and increased landscaping in street areas. These changes will reduce overall runoff volumes. Permeable areas in the proposal form about 18%.</td>
<td></td>
</tr>
<tr>
<td>Categories</td>
<td>Indicators</td>
<td>Parameters</td>
<td>Current Area Situation</td>
<td>Proposed Scenario</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------------</td>
<td>------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Amenities</td>
<td>Proximity to services</td>
<td>Index of accessibility to services</td>
<td>Community facilities are unevenly distributed and are 6% of current land use.</td>
<td>Proposed local centers &amp; special nodes enhance services provisions which are 7% of total land use.</td>
</tr>
<tr>
<td></td>
<td>Entertainment equipment</td>
<td>Index of accessibility to entertainment equipment</td>
<td>Entertainment and cultural uses form around 2% of current land use.</td>
<td>Entertainment and cultural uses have been increased to form 8% of land use in the area.</td>
</tr>
<tr>
<td></td>
<td>Local production of food</td>
<td>Index of existing structures</td>
<td>No local food production areas available.</td>
<td>The plan mentioned the creation of a localized approach with sustainable food production in project goals. But it does not show any allocation of space for food farming or retailing.</td>
</tr>
<tr>
<td>Mobility</td>
<td>Public transportation</td>
<td>Index of quality and frequency of public transport</td>
<td>The area is a focal point of the current limited public transport system in the City (3% of all trips in the city). The Central Area is a key hub within this network of formal and informal public journeys within the City. The current public transit include bus service that is known with poor quality.</td>
<td>The area is a primary node within the proposed public transit networks. The Blue Line and the Red Line cross it providing good levels of service to the majority of it. Local level connections via bus and BRT networks are designed to enhance connectivity in inner districts. Total 7 train stations proposed and over 60 bus stations.</td>
</tr>
<tr>
<td></td>
<td>Pedestrian accessibility</td>
<td>Index of pedestrian accessibility</td>
<td>The area lacks public open space and is characterized by limited 'local' connections within residential neighborhoods with only few streets with sidewalks, creating a poor quality pedestrian environment.</td>
<td>A pedestrian network is proposed to connect the area with boulevards along main streets with upgraded squares and open spaces. A Heritage trail is created providing a pedestrian network linking heritage buildings.</td>
</tr>
<tr>
<td></td>
<td>Cycle paths network</td>
<td>Index of cycle paths network quality</td>
<td>No cycling infrastructure</td>
<td>A network of cycling paths is proposed along main streets such as Madian Road &amp; Batha Street.</td>
</tr>
<tr>
<td>Integration</td>
<td>Percentage of affordable</td>
<td>Percentage of affordable housing</td>
<td>Residential units in the area have some of the city lowest rates, at circa 525per m^2. Approximately 82,200 housing units are recorded n the area most of which are in poor conditions.</td>
<td>A range of housing typologies had been proposed (84,700 units) to accommodate different economic groups as the flowing; - High quality &amp; high end housing in proximity to the work place= 21% - Medium / low income family housing= 40% - Medium / low income housing along mixed use corridors= 15% - Low income housing for expatriate &amp; locals= 24%</td>
</tr>
<tr>
<td>and social</td>
<td>inclusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local and cultural identity</td>
<td>Index of population participation</td>
<td>Non</td>
<td>No public participation in the developed plan had been reported.</td>
<td></td>
</tr>
</tbody>
</table>
Table (4) summarises the final results, showing what sustainable categories were enhanced and what were not specified in the regeneration proposal. The analysis shows that the proposed plan ticks several points when it comes to sustainability and it contributes to the main goals set to turn the deteriorated area into a vibrant city centre that have the power to form a strong cultural character and to provide several opportunities for work, living, and leisure.

Within the regeneration proposal, great enhancements are seen regarding transportation services of train and BRT networks currently under construction. This is followed by the introduction of activity corridors and special nodes as Transit oriented development areas which will be able to enhance the provision of services in the area as a whole. The urban design is improved as well, with the creation of more green and public spaces which are complemented by a new infrastructure for walking and cycling to connect the inner districts and to create an attractive public realm. Also, Strong existing elements that contribute to the identity of the central down town area such as souks and commercial areas are retained and enhanced, in addition to the main existing historic elements that are to be rehabilitated and linked via a cultural path which will further emphasis their significance.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Indicators</th>
<th>Parameters</th>
<th>Current Area Situation</th>
<th>Proposed Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employment promotion &amp; investment</td>
<td>Economic viability</td>
<td>Index of local economy</td>
<td>Significant levels of poverty in the area are reflected by poor living conditions, low incomes and a decaying urban fabric which should not characterize the centre of a modern international city. At least 50% of families residing in the Central Area live below the poverty line compared to 15% in Riyadh as a whole.</td>
<td>The area is likely to keep its role as a focus for commerce industrial activity and new job opportunities will be created in these sectors; Professional and business services (16%), Education and health (6%), Creative and cultural industries (10%), government services (25%). The economy of the area would become well diversified providing a substantial increase to Riyadh’s GDP. Which will add an amount of 77SAR billion (US$20.6bn) in terms of GVA.</td>
</tr>
<tr>
<td>Employability</td>
<td>Index of employability</td>
<td></td>
<td>The area has a high rate of unemployment reported at 20% in 2004 compared to 12% in KSA as a whole. 9% of the areas workforces are Saudi citizens working in the public sector. The balance of 91% is non Saudi and work primarily on construction, industrial and trade sectors. Of the 430,000 residents approximately 195,000 are in employment.</td>
<td>During the construction phase 22,000 jobs in KSA per year in which 17,000 are in central area. Following operational phase 195,000 new jobs are anticipated, of which 160,000 are in central area</td>
</tr>
<tr>
<td>Sustainable buildings</td>
<td>Index Sustainable buildings</td>
<td></td>
<td>NON</td>
<td>NON</td>
</tr>
</tbody>
</table>
Other enhancements include green areas, which had been extended with several linear green boulevards proposed as connectors between districts. Also, an important improvement is concerned with the deteriorated housing areas which to be improved providing a variety of typologies appropriate for all people from different economic backgrounds especially those in need for affordable housing.

However, there were some indicators that were not clearly identified within the proposal. As shown in table (4), the environmental category shows that 50% of total indicators were clearly specified and it shows that indicators related to the built environment rehabilitation were presented as a set of recommendations without explaining actual percentage of buildings to be rehabilitated/reused and what type of uses are suggested. Other indicators concerning renewable energy and water reused did not indicate percentages of energy and water to be conserved.

As for the social category, 75% of indicators were specified. However, for local food production, there were no areas allocated within the plan for farming to provide for local foods. In addition, no record was found regarding public participation that is involving area residents which is a real weakness.

Hence, the economy category presented a good specification for the surplus expected from the development and the generated employment opportunities which is likely to contribute strongly towards enhancement of an underutilized area like the central downtown. Finally, the issue of sustainable buildings was not
specified which can have great impact on efforts to reduce energy and water consumption in addition to encouraging responsible use of materials in the area.

**Discussion & Conclusion**

The interest in evaluating systems is increasing among authorities, investors, and developers, since this can allow the comparison between urban areas, serving to support decision making processes, and benefiting authorities, planners and designers during this process. The evaluation is likely to utilize frameworks with several indicators which are assessing the sustainability of urban developments, demonstrating their environmental, economic, and social benefits to communities. (Castanheira & Bragança, 2014)

This paper presented an analysis for the development plan for the downtown area in the Saudi capital Riyadh. The plan is proposing a regeneration process to enhance the poor physical environment which characterizes much of the area, combined with lack of modern infrastructure, traffic congestion, social disadvantage and crime. These issues had been targeted in the proposal with the goal of enhancing sustainability as well.

The analysis was conducted using the SBTool-UP methodology investigating how the proposal is actually tackling sustainable development. A set of indicators were selected and a comparison between the current situation and the proposal against each indicator was presented. The results show that the proposed regeneration framework was successful in addressing the majority of indicators, which is expected to contribute to the enhancement of quality in the urban environment and help form a starting point toward transforming Riyadh as a whole into a sustainable city.

However, there were several indicators that were not addressed in the proposal, in which three are considered to be a major downfall within the development framework. The first is regarding building rehabilitation and reuse. As shown in the plan that major historic elements are to be integrated with the larger scheme, but there was no mention of other structures that can be reused or recycled. This should be taken in consideration keeping in mind that management of materials and demolition waste is an important part of any sustainable development initiative. The other issue is related to water reuse and renewable energy production which need to be more specific of how the proposed solutions will contribute to the conservation of water and energy. This is very essential specially with energy demand increasing as a result of population growth in the city.

In addition, green building design needs to be included within the future detailed plans and to be integrated into the area’s Development Regulations to better enhance sustainable performance for energy, water, and materials.

One final issue is public participation, which has not been addressed in the plan although it forms a real challenge when such a development is being considered. It is widely accepted that in democratic societies urban regeneration processes should
adopt governance approaches that involve multiple stakeholders including residents and other civil communities of interest (Czischke et al, 2015). However, this issue needs to be tackled in the downtown area to avoid clashes that could lead to conflicts of interest between different stakeholders especially in this case where plans for relocation and resettlement of different population groups within the area are present. Although the proposal argues that this will provide for better quality housing, the effects of such severe demographic changes remains something that cannot be addressed without consulting with the local community.

References

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Walkability as an Urban Indicator for a Sustainable Built Environment

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Abstract: As environmental problems became global in scale in late 1990’s, sustainability became a widely used term. Although there is a consensus about why environmental problems occurred and how cities can become sustainable again, there is not any evaluation method that objectively measures sustainability. As objective criteria, urban indicators were developed aiming to ensure a great base for evaluating the sustainability performance of built environment. Since their emergence, more than 700 urban indicator metrics were developed but still there is no urban indicators metric available in global standards. Even all metrics differ in terms of their concept and scope, the common ground of all is that the indicators are shaped around three main aspects: environmental, economic and social.

It is also accepted that being dependent on private cars due to the unrestrained growth in cities, people tend to walk less. In other words, walkability quality of urban started to become impoverished. As walkability started to be discussed within the architectural media, it has been thought as one of the most important aspects that makes cities sustainable.

In this study as literature review, the general properties of urban indicators and how they can serve for a sustainable and better built environment are defined. Afterwards, how walkability can contribute to these indicators or in which part walkability can be involved in these indicators are discussed. It is resulted that walkability is one of the most important indicators that can be listed both under environmental, economic and social aspects of sustainable built environment.

Keywords: walkability, urban indicators, sustainability, built environment

Part I: Introduction

With the rapid and intensive integration of technological improvements into our everyday lives from several angles starting from 1900’s, some crucial changes started to be included into daily routines like computer, mobile phones, electricity, internet connection, transportation and other technologic devices and tools. Referringly, human started to consume more energy and natural resources. Also, more energy waste started to be swept into nature. When the consumption of energy and oscillation of energy used reached a crucial threshold, sustainability became a buzzword to be used. Although sustainability became a widely discussed issue from several points of views and from various different disciplines (Barros, 2014), there is still no objective measure to analyze and measure it (Moudon et. al., 2006). For objectively measuring sustainability status and condition of existing built environment, urban indicators started to be developed and proposed. Several urban sustainability indicators (USIs) have been developed for different aims, target user profiles or geographic areas and they differ in terms of their detailed content however what is common for all is that the super group of their content can be classified into 3 aspects: environmental, social and economic.

In addition to the technological developments which are resulted with sustainability problems in built environment, cities also tend to get bigger than they were in ancient which makes walking impossible as a transportation mode because of the destinations between two points of walking which gets farther. As a mode of transportation, people started to choose private automobiles rather than walking and public transportation (Azmi
Karim, 2012). This transportation mode changes in everyday lives are resulted with some problems both in people and in environment. People who started to walk less tend to have some health problems like obesity (Bahrainy & Khosravi, 2013), cardiovascular problems or heart diseases and also feeling less attached to his living environment. From environmental point of view, CO2 emission level started to increase and more natural resources started to be consumed. Due to this direct relation between walking and sustainability, it was started to be discussed that the act of walking or more walkable environments can directly make contribution to environmental problems and recover the problems that lead to sustainability.

In this study, Part II and Part III compose the literature review parts. In Part II; sustainability and urban sustainability is described. Afterwards, the urban sustainability indicators (USIs) are explained with their main functions, their types and their content. In Part III, the issue of walkability is briefly described as following: how it emerged and the definitions of walkability, by which disciplines walkability is studied, how walkability studies can be clustered, walkability criteria, how and through which methods walkability can be measured and the benefits of walkable environments. In the last part, Part IV and Part V; it is analysed that how walkability can be a part of urban sustainability indicators and from which aspects walkability can contribute to that indicators.

**Part II: Urban Sustainability**

As defined by Heintz (2004), sustainability is a theme which defines a health, dynamic situation of Earth and the productive balance of existences in harmony with human social and economic systems that have an interaction without any bias to the non-human – built – elements, the environment. It should also be viewed as a philosophy which afford people awareness of the outcomes of the actions and promote people to think over issues, disciplines and boundaries (Flint, 2013, pp. 26).

As a subtitle under sustainability, urban sustainability can be described as the process of built environment development which satisfies the people’s needs and requirements when preventing unacceptable social or environmental impacts (Hamilton et al, 2002). For Wu (2014), urban sustainability is “an adaptive process of facilitating and maintaining a virtual cycle between ecosystem services and human well-being through concerted”.

Both sustainability and urban sustainability are complex organisms which are composed of several aspects. In Figure 1, the environmental, social and economic aspects of sustainability can be seen which also shows the necessary interrelations between each.

The characteristics of each aspect are as following (Flint, 2013):

- **Environmental**: understanding of natural system processes of landscapes, watersheds and seas for preserving these systems
- **Social**: equal access to jobs, education, natural resources and services for all, total societal welfare, access to fair conflict resolution
- **Economic**: protection or enhancement of natural resource quantities through improvements in management practices and policies, technology, efficiency and life style changes
Urban Sustainability Indicators

Urban sustainability indicators (USIs) are developed and proposed for objectively measuring urban sustainability. They become well-known for analyzing and evaluating built environment’s sustainability level (Deng et al, 2017). Urban sustainability indicators are advantageous for collecting required data about urban status and implementing this required data into urban policies and actions (Westfall & De Villa, 2001).

Main Functions of Indicators

The 2 main functions of urban sustainability indicators are as following (Olofsson & Freij, 2017):

- Decreasing the quantity of parameters and criteria which are used for giving the concrete result about the current urban situation
- Vulgarising the data collection, interaction and communication process depending on the users’ needs

In addition to these functions, USIs must also collect data and inform related people about the process and goals for sustainable development.

Types of Indicators

For Westfall and De Villa (2001), the types of sustainability indicators are as following:

- **Performance Indicators**: Measuring the performance of organizations, sectors or cities and identifying the departments, districts or policies which may meet the required aims
• **Issue-Based Indicators**: Drawing attention to specific points or issues like crime, safety, unemployment, urban sprawl, air quality, etc.

• **Needs Indicators**: Measuring the needs to ensure resources to the group that needs most like poverty and deprivation

**Content of Indicators**

There are several and various number of urban sustainability indicators that are developed for a specific aim, problem or geographic area. Although there are numerous and they differ from each other in details, they are commonly shaped around 3 main topics: social, economic and environmental (Andreason et al, 2011). In the following (Table 1), there is a framework that is developed by referencing to HUD Working Group which shows the main groups and required elements and goals for each theme:

<table>
<thead>
<tr>
<th>Dimensions of Sustainable Urban Development</th>
<th>Elements Necessary for Sustainable Urban Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Wellbeing</td>
<td>Health</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
</tr>
<tr>
<td></td>
<td>Access to decent (affordable) housing &amp; services</td>
</tr>
<tr>
<td></td>
<td>Access to public recreation &amp; open space</td>
</tr>
<tr>
<td></td>
<td>Access to a variety of transportation options</td>
</tr>
<tr>
<td>Economic Opportunity</td>
<td>A diversified &amp; competitive local &amp; regional economy</td>
</tr>
<tr>
<td></td>
<td>Transportation &amp; other infrastructure coordinated with land use</td>
</tr>
<tr>
<td></td>
<td>Growth plants that leverage existing assets</td>
</tr>
<tr>
<td></td>
<td>Access to capital &amp; credit</td>
</tr>
<tr>
<td></td>
<td>Access to education, jobs &amp; training</td>
</tr>
<tr>
<td>Environmental Quality</td>
<td>Efficient land use</td>
</tr>
<tr>
<td></td>
<td>Use of renewable resources</td>
</tr>
<tr>
<td></td>
<td>Waste/pollution minimization &amp; management</td>
</tr>
<tr>
<td></td>
<td>Climate change &amp; natural disaster mitigation, adaptation &amp; resilience</td>
</tr>
<tr>
<td></td>
<td>Carbon efficient &amp; environmentally sound transportation</td>
</tr>
<tr>
<td></td>
<td>A diverse natural environment &amp; functional ecological systems</td>
</tr>
</tbody>
</table>

**PART III: Walkability**

**Roots & Definitions**

Starting from its first emergence in both academic field and sector, it is one of the most mentioned properties that identify liveability in urban scale (Ghadimkhani, 2011). Although it is like a buzzword in current urban planning and design professional language (Azmi & Karim, 2012), the words origin is still not clear. As it was cited by Fitzimons (2013), Advocate Dan Burden predicts that walkability issue has started only as movement in 1983
but the concept and term came afterwards in 1992-93. On the other hand, as it was cited by Pak and Verbeke (N.D.), it is also possible to trace the origins of walkability to Howard’s Garden City and Drummond’s Chicago Plans.

In addition to uncertainty of the roots and emergence of walkability, there is also no definite and concrete meaning of walkability. Although there is not a common definition of walkability, starting from 1990’s; some researchers tried to make their own definition from their own point of view as following:

- The quality of walking conditions, including safety, comfort and convenience (Litman, 2003)
- The extent to which the built environment is friendly to the presence of people living, shopping, visiting, enjoying or spending time in an area (Abley, 2005)
- Where the activity of walking can be more readily performed (Gauvin et al, 2005)
- A measure of the extent to which characteristics of the built environment and land use are conducive to neighborhood residents walking for either leisure, exercise, to access services or to get to work (Leslie et al, 2005)
- The degree to which an area within walking distance of a property encourages walking for recreational or functional purposes (Pivo & Fisher, 2009)
- One of the most discussed properties of the liveability in public spaces (Ghadimkhani, 2011)
- Which should meet the needs of residents and it should match through the built environment (Manaugh & El-Geneidy, 2011)
- The extent to which the built environment facilitates or hinders walking for purposes of daily living (Andrews et al, 2012)
- To what extent the neighborhood meets the needs of the residents (Azmi & Karim, 2012)
- A measure of the effectiveness of community design in promoting walking and bicycling as alternatives to driving cars to reach shopping, schools and other common destinations (Rattan et al, 2012)
- Which bonds several neighborhood characteristics together like land use mix, residential density in one hand and using geospatial design techniques to stick walkability to individual aspect together on the other (Riley et al, 2013)

**Being Studied by Several Disciplines**

Starting from its very first emergence, walkability has discussed by several different disciplines due to the reason that walkability is an issue that has several different concerns. The disciplines that discuss and use walkability can be listed as transportation, new urbanism, behavioural medicine, public health, philosophy, anthropology, sociology, psychology, engineering and architecture. While being studied by several different disciplines, the different perspectives of the term are being taken into consideration (Cambra, 2012). As stated by Lee and Moudon (2004), this multidisciplinary aspect of walkability guide and enable researchers to a better understanding of several point of views.

**Clustering Walkability Researches**

Because that walkability is studied by several different disciplines, there are many different researches, articles or thesis that covers the issue of walkability from different
Although the researches can be sub-grouped into several items, they can be grouped into 5 main themes (Andrews et al, 2012) as following:

- **Measuring walkability** – in which one walkability measurement tool is selected and the tool is conducted in the selected case study area (street, neighborhood, city, etc.)
- **Potential facilitators of walkability** – in which demographic and social variables related to social composition of places (age, ethnicity, socio-economic status) and contextual factors of places (availability, land use designations, sidewalks, crossings, etc.) are used as research variables
- **Walkability and diverse quantifiable outcomes** – in which numeric data (walking rates, distances, health status data sets) is analysed under walkability or related to walkability
- **Perceptions of walkability** – in which more perceptual aspects (familiarity, safety, etc.) rather than physical ones are searched regarding walkability
- **Production and form of walkable environments** – in which the aim is more application oriented like urban planning composition or proposal

**Criteria**

The issue of walkability is a very well known and widely used term which tried to be objectively measured. For objectively measuring walkability, a criteria is tried to be set by different researchers however, still there is no common walkability criteria or checklist. Some of the walkability criteria proposals made by individuals are as following:

- Large parcels, fewer roads, minimal land use diversity, few retail centres (Coffee et al, 2013)
- Residential land use, mixed-use, presence of green space, aesthetic factors (Andrews et al, 2012)
- Greater residential density, mixed land use, greater street connectivity (Gauvin et al, 2005)
- Population density, street network pattern, land use mix, retail access, accessibility to arrange public facilities (Dyck et al, 2010)
- Continuity, cohesion of developments, safety (Bahrainy & Khosravi, 2013)
- Connectivity, concenience, comfort, conviviality, conspicuous, coexistence, commitment (Cambra, 2012)
- Residential density, mixture of land uses, connected streets (Choi, 2012)
- Walking destinations, street connectivity, sidewalk access (Duncan et al, 2011)
- Land use mix, resident density, street connectivity (Frank & Pivo, 1994)
- Population density, street network pattern, land use mix, retail access, accessibility to facilities (Lee & Moudon, 2006)
- Street connectivity, high land use mix, high residential density (Frank et al, 2005)
- Density, diversity, design, area in retail use (Frank et al, 2010)
- Compact, connected urban, mixed use densities, land uses (Gebel et al, 2009)
- Diversity of land uses, access to facilities, street connectivity (Krizek et al, 2010)
- Proximity, connectivity (Owen et al, 2007)
• Connectivity, linkage with other transportation modes, land use patterns, safety, path context quality, spatial definitions, overall explorability (Soutworth, 2005)

In addition to individually based criteria, there are some hard-copy and web-based walkability measurement tools in which they all set their own criteria. Although all individually based or research based tools set their own criteria, broadly the criteria they set can be grouped into 3 main themes: physical, psychological and socio-spatial aspects of the walking act.

**Measurement Tools & Methods**

For analyzing and measuring the walkability in built environment, several different tools can be used as following: audit tools, checklists, inventories, level-of-service scales and surveys (Cambra, 2012).

As the methods of the tools, the mostly used methods for assessing walkability and their properties can be listed as below:

• **Survey**: Allows the researcher to measure how built environment attributes are perceived (Cambra, 2012) / Have problems with reliability, validity, low response rates and a biased sample of respondents (Duncan et al, 2011).
• **Direct observation**: Can be the most reliable method for collecting data (Cambra, 2012) / Can be very laborious (time-intensive) (Duncan et al, 2011).
• **GIS Technologies**: Helps in the mapping and analyzing data regardless of how it is collected (Cambra, 2012) / The criteria can be assessed objectively using this system (Dyck et al, 2009) / Requires specialized expertise, can be time-intensive and GIS data layers may not be accessible for certain geographic regions (Duncan et al, 2011).
• **Motion detectors**: Accelerometers and pedometers can capture the physical activity objectively (Meester et al, 2013).
• **Self reported measures**: May have a same-source bias (Duncan et al, 2011).

According to the aim, scale and scope of the research or the study, the proper tool and method can be selected through the researcher.

**Benefits**

As cited by Ghadimkhani (2011), walkable neighborhoods have several benefits for both the residents and the visitors. These benefits can be listed as following:

• **Basic mobility**: Increases the level of being mobile by walking or cycling
• **Community liveability**: Contributes to the social and environmental quality which can be perceived by residents and visitors / Increases the attractiveness and safety of the area
• **Community cohesion**: Increases the quality of the area / Affects the quality of the relation between residents / Multiplies the sense of community by composing relation with others from different social levels
• **Economic development**: Increases the number of customer / Commercial areas become more attractive / **Consumer cost savings**: Chosing walking compared to motorized transportation which decreases the residents expenses
• **Public health**: Effective over health both physically and mentally / Prevents heart disease, hypertension, stroke, diabetes, obesity, osteoporosis, cancer, depression, loneliness

To sum up, the benefits of walkability – *non-motorized transportation mode* – are not only limited to decrease in car use and in energy consumption but also have impact upon increased level of liveability, community cohesion and social inclusion. Also, it improves public health, accessibility and user convenience (Cheshmehzangi, 2015).

**PART IV: Analysis**

In the analysis part, it will be discussed how walkability can contribute or be a part of urban sustainability indicators that were developed by Andreason et. al. (2011) as it was shown in Table 1 by referring to HUD Working Group. Possible contributions of walkability into each indicator will be analyzed deeply as following.

**Social Wellbeing**

• **Health**: Walkability can contribute to health from several aspects which correlativealy interact with sustainability. Urban with higher walkable quality makes people healthier as following: more active, lower cardiovascular disease risk, lower heart attack risk, lower obesity rate, lower diabetes risk and greater psychological state.

• **Safety**: Walkable environments should be safe in several aspects like having adequate and sufficient dimensions like in width and height, having the required infrastructure for walking and having the adequate lighting in which all also contribute to general understanding of safety in urban scale and social wellbeing.

• **Access to descent – affordable – housing and services**: With the act of walking, there is an opportunity to reach and take advantage of more affordable facilities like housing and services without any friction. In other words, the more walkable neighborhood, the more fair and equal access to life serving facilities.

• **Access to public recreation and open space**: Although public recreation areas and open spaces are constructed physically, these built environment items can only become alive with people using them. Therefore, walking can be one of the only acts that make them alive and it can be one of the only ways to access them to support social wellbeing. With being part of public and open space with the act of walking, social belonging can be provided.

• **Access to a variety of transportation options**: Having an access to several different transportation choices can be one of the most important items for providing social wellbeing. Through the act of walking and with the help of walkable environments, one of the transportation modes becomes already chosen – “walking”. For some, one of the important criteria of walkable environment is to provide different public transportation modes. Therefore, in a walkable environment; both walking can be a choice of transportation and also other public services are provided.
**Economic Opportunity**

- **A diversified and competitive local and regional economy:** Within the walkable neighborhoods, people tend to walk either as transportation or leisurely activity – like going around. The entries of walkable environment invite people to walk around for aim or not. Within the walkable environment because that residents tend to go around and shop by walking, it creates a competitive medium in economy like local shops or bazaars. As part of the walkable environment criteria, different number and type of amenities will work on behalf of a greater economic opportunity for a sustainable environment.

- **Transportation and other infrastructure coordinated with land use:** Within the walkable built environment, the balance between transportation, infrastructure and land use is a must which is also a must for sustainable environment.

- **Growth plans that leverage existing assets:** For enhancing economic opportunities, proposing plans for strengthening current and existing resources is a thing to do. The act of walking is an activity that requires nothing more than an individual and ambition. In other words, there is no need for any resource for walking. Therefore, within the walkable environments; the natural resources will not be diminished and that may be resulted with the application easiness of growth plans.

- **Access to capital and credit:** Activity of walking is a movement that is possible for all and what makes all equal regarding the age, ethnicity, gender, background, etc. Within the walkable environment, there is equal chance for everyone to access capital and credit. Also, the walkable environments have different amenities and facilities existing in the same neighborhood. In other words, there is a mix land use between housing and public facilities. This mixed land use makes capital and credit always existing.

- **Access to education, jobs and training:** Regarding the property of a walkable neighborhood or for defining an area as walkable, there should be some facilities like education, art, health and sport. These facilities are accessible for all through the act of walking physically. These facilities’ existence both serve for economic opportunity as job opportunity and as an amenity to be used by residents.

**Environmental Quality**

- **Efficient land use:** For creating a walkable neighborhood or environment, it is important to achieve a balance in land use which is called mixed-land use. The mixed-land use can be achieved to create a balance between housing units and commercial units. This balance in-between both serves for environmental quality in terms of energy consumption and waste emission. The same balance which serves for environmental quality also promotes the act of walkability and liveability.

- **Use of renewable resources:** Walkable environments with the idea of decreasing car dependency and decreasing the level of energy consumption, it has idea in it’s background to take resource management seriously, which can be applied most easily with the use of renewable resources.
• **Waste/pollution minimization and management**: With minimizing the car usage and waste emission in walkable environments, walkability directly serves for sustainability. In our modern cities which can be hard to set energy consumption and car usage into zero, it can be managed through the act of walking.

• **Climate change and natural disaster mitigation, adaptation and resilience**: The very main reasons of climate change and natural disaster is the uncontrolled use of energies which are actually limited in nature. The greatest energy consumption in our everyday lives is caused by automobile usage and the greatest waste emission is caused again due to the emissions made through car exhausts. The act of walking can be the optimal solution to serve for sustainability.

• **Carbon efficient, environmentally sound transportation**: In today’s modern cities, the greatest ratio of transportation mode is private automobiles. Secondly, public transportations are chosen like bus, mini bus, ship, tramway or train. Due to the limited time we have in our daily routines, walking is not that much performed as transportation. However, it is obvious that walking is the only way of transportation in addition to bicycling that does not consume any energy and it can be the most environmentally friendly way of transportation.

• **A diverse natural environment and functional ecological systems**: To give a chance for various and diverse ecological systems and organisms in our built environment, the carbon emission should be minimized and also there should be a balanced land use for giving them chance to take place. For aiming this, walkable environment criteria can enable this diversity.

**PART V: Conclusion**

As it is all well-known, sustainability is such a wide term which has several different aspects to be discussed. From various point of views, sustainability can be enhanced or provided.

Whereas the act of walking is seen only as a physical act; when walkability is analysed from that point of view, it can be seen that walkability should be one of the subtitles under sustainability in urban design. As urban sustainability indicators of walkability, the act of walking or walkable environment; it is seen that walkability can contribute to social well-being through creating healthier environment and residents, creating both physically and psychologically safe neighborhoods, equal and fair access to housing, retrieval to open and public spaces and having right to chose from several transportation options. Also walkable environment can contribute to economic opportunity via creating local economy, transportation-land use balance, having an equal access to several different amenities and facilities like school, work, health and sport. Lastly, walkability can make a great contribution to environmental quality with zero energy consumption and zero waste emission, mixed-land use and being as the greatest way of transportation.

It is obvious and can be seen from the analysis that walkability can make a great contribution to three aspects of sustainability (Andreason et al, 2011). Because that walkability contributes to each parameter at the same time, it makes contribution to directly sustainability which is the intersection of three aspects.
Table 2. Sustainable Development Indicators (Andreason et al, 2011)

<table>
<thead>
<tr>
<th>Dimensions of Sustainable Urban Development</th>
<th>Contributions of Walkability into Sustainable Urban Development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Social Wellbeing</strong></td>
<td>Health – <em>lower risk of health problems &amp; being more active</em></td>
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<tr>
<td></td>
<td>Safety – <em>proper dimensions, required infrastructure &amp; lighting in urban</em></td>
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<tr>
<td></td>
<td>Access to decent (affordable) housing &amp; services – <em>fair &amp; equal access to facilities</em></td>
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<td></td>
<td>Access to public recreation &amp; open space – <em>social belonging through walking</em></td>
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<td></td>
<td>Access to a variety of transportation options – <em>walking as a transportation choice</em></td>
</tr>
<tr>
<td><strong>Economic Opportunity</strong></td>
<td>A diversified &amp; competitive local &amp; regional economy – <em>going around &amp; shopping by walking</em></td>
</tr>
<tr>
<td></td>
<td>Transportation &amp; other infrastructure coordinated with land use – <em>mixed-land use balance</em></td>
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<td></td>
<td>Growth plants that leverage existing assets – <em>no resource needed for walking</em></td>
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<td></td>
<td>Access to capital &amp; credit – <em>walking as an equal chance for all</em></td>
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<tr>
<td></td>
<td>Access to education, jobs &amp; training – <em>facilities accessible through walking</em></td>
</tr>
<tr>
<td><strong>Environmental Quality</strong></td>
<td>Efficient land use – <em>balance in-between residential &amp; commercial units</em></td>
</tr>
<tr>
<td></td>
<td>Use of renewable resources – <em>resource management through walking</em></td>
</tr>
<tr>
<td></td>
<td>Waste/pollution minimization &amp; management – <em>minimised waste emission</em></td>
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<td></td>
<td>Climate change &amp; natural disaster mitigation, adaptation &amp; resilience – <em>walking for minimizing energy consumption</em></td>
</tr>
<tr>
<td></td>
<td>Carbon efficient &amp; environmentally sound transportation – <em>walking as eco-friendly way of transportation</em></td>
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<tr>
<td></td>
<td>A diverse natural environment &amp; functional ecological systems – <em>lower lever of carbon emission through walking for diversity</em></td>
</tr>
</tbody>
</table>

To sum up, walkability can be defined as the common criteria for sustainability through serving social wellbeing, economic opportunity and environmental quality which shows that walking is both a physical, psychological and socio-spatial act; even though walking is still interpreted and seen only as a physical movement which leads us from one point to another.
PART VI: References


Reconsidering the Design of Urban Communities in the Hot Arid Regions of the Middle East: The Search for More Relevant and Sustainable Urban Guidelines

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Abstract:
The urban fabric of cities located in hot, arid regions across the Middle East has changed drastically in recent years. A lack of planning and urban design guidelines has led to sprawling cities suffering from pollution, a lack of green space, dilapidated infrastructure, congestion and high population density. Response to these critical issues has simply centred on design practices that create more new, gated communities. These gated communities implement models that are alien and unsustainable in this region and fragment the urban fabric of the society. There is an increasing need to consider more relevant and sustainable solutions for the design of new settlements that build on the heritage of the region and objectively respond to the present circumstances. This paper aims to establish a series of design guidelines from which can evolve a more relevant and sustainable way of living in this urban context. Therefore, historic cities of the region were studied and analysed with the intention of interpreting emerging principles in way relevant to the contemporary urban context. This comprehensive, comparative analysis was the basis of a set of design guidelines that could be relevant for future development in this region. Furthermore, these principles will be tested through a schematic, master plan design for an urban settlement located in New Cairo. The project presents an alternative to current urban practices in the region and will hopefully inspire others to consider a new approach to urban design in the hot arid regions of the Middle East.

Keywords: Sustainable urban design, Traditional settlements, Hot arid regions

Introduction

The aim of this paper is to find a more appropriate approach to building residential developments than what has been adopted since the second half of the twentieth century in the Arab hot arid region. Cairo has been selected as an example of Arab cities, as its harsh circumstances as one of the world megalopolises, that include but are not limited to pollution, congestion, lack of green spaces, deteriorated infrastructure and high population growth, mean that a new urban and architectural approach is needed. To fulfil this goal, a proposal of a residential development is presented to examine the validity of the design in a contemporary context. The design of the proposal is based on a set of design guidelines that are based on what has been traditionally built in the region.

The Urban Context

Throughout its modern history, Cairo had a wide diversity of internal urban division characteristics, as while a central business district, high class residential areas, low class
residential areas had been evolving, other unplanned areas started to appear. In general all of Cairo’s urban divisions had high building and population densities, and were characterized by the presence of commercial, public and sometimes industrial uses within the residential areas. Unfortunately by the beginning of the 21st century, Cairo could be perceived as fragmented into four different urban forms, which are: conventional neighbourhoods, informal areas, sprawl and gated communities. Such fragmentation of urban fabric led to a strong fragmentation of society, where some social classes are keen to move away from the rest, a phenomena that might lead to severe social unrest in the near future.

A. Conventional Neighbourhoods

The neighbourhoods of Cairo (founded in 969AD), have changed throughout its long history, although its “modernization” could be dated as early as Mohamed Ali’s accession to power (reigned from 1805 till 1848). However, his Grandson, Ismail Pacha (reigned from 1863 till 1879) was keen to make Egypt part of Europe. He was influenced by Haussmann plans for the re-planning of Paris, and implemented these plans in the area surrounding the old parts of Cairo. Nile bridges were built, leading to the expansion of Cairo on both banks, and numerous new buildings were rapidly erected such as the opera, theatres, palaces, in addition to the creation of parks and boulevards to mark the ceremonial opening of the Suez Canal. Accordingly Cairo was separated into two distinct parts: the old closed part and the new European-type town to the West of it.

During the end of the 19th century and the beginning of the 20th century, Egypt was enjoying an economic boom, resulting from cotton production and the inauguration of the Suez Canal with all the import-export trade, banking and finance depending on it. The socio-economic prosperity of Cairo led to the creation of new districts that stretched the limits of the city. However, the turbulent decades of the second half of the 20th century affected Cairo’s urban fabric in a drastic way.

In general, the conventional neighbourhoods are characterized by a dense compact fabric, where streets are narrow (approximately 10 meters wide), and buildings are high, (almost five stories high). Mixed land use is common, as shops and most services (clinics, office spaces) usually exist everywhere in the ground and first floors of most residential buildings. Apartment blocks became almost the only housing typology available as most of the villas have been recently demolished. However these neighbourhoods suffer from pollution, congestion, dilapidated infrastructure and lack of maintenance. The residents use a not very convenient or affordable system of mass transportation and taxis. Private cars are not available for most people, and bicycles are rarely used.

B. Informal areas

Informal areas take the form of what could be called unplanned spontaneous urban areas. Where houses are constructed without compliance to the established procedures, laws and regulations. Cairo’s informal areas are in general characterized by haphazard construction, where the apartment blocks are the main housing typology. The informal areas are also characterized by the diversity of uses and the high population density and high population growth rate. The residents of the informal areas are a mixture of workers in all professions, employees, and newly wed university graduates, in addition to migrants from the rural areas.
The informal areas began growing in Cairo in the early 1960s, on agricultural land at first, which were adjacent to the north and west of Cairo, and on the desert fringes to the east. The phenomenon was ignored by the officials, who considered it happening outside the city limits, or outside their area of authority. During the war years of 1976 till the mid 1970s, the informal areas continued to grow to absorb almost one million people evacuated from the Suez Canal zone in addition to internal migration from the Nile Delta and Valley. The economic changes that occurred in Egypt in 1974, and the adaptation of the liberalization policy, led to the spread of informal areas on a large scale. Also hundreds of thousands of Egyptians worked in the oil-rich Arab countries, and almost all their savings and remittances were transformed into houses in informal areas. As a consequence of the rapid population growth, high internal migration patterns from the countryside to the capital, and a shortage in affordable housing supply, by the 1980s, informal housing became the only viable housing option for the country’s urban poor. David Sims, an esteemed expert on Egypt’s housing situation, estimates that in 2009, Greater Cairo has pushed 63% of its 17 million inhabitants into informal areas (Sims, 2010)

Among the advantages of living in an informal area, are the affordability of the dwelling, accessibility to central parts of Cairo, the strong social ties among the inhabitants, as in most informal areas relatives can live in the same vicinity, and the availability of shopping and working opportunities within walking distances, which is a result of the high density of the informal areas (Sims, 2010). In general most of the informal areas contain a heterogeneous mix of inhabitants with a wide range of incomes, because of the area’s development over time. However the disadvantages of living in an informal area include, the lack of natural light and ventilation as high buildings surround narrow lanes, the total absence of open spaces or green areas, the difficulty of maneuvering within the street network for ambulances during emergences, and of course the non-existence of parking spaces. In addition to the poor quality or insufficiency of basic services such as the health and educational facilities. While the residents typically plan, finance, and build their own communities, they do not have the financial resources to also construct basic infrastructure like waste disposal and drainage facilities. As these areas receive little assistance from charitable or non-governmental organizations, these facilities are often inadequate, resulting in degraded and unhealthy living and poor environmental conditions.

C. Urban sprawl

Urban sprawl is a pattern of low-density development that is characterized by dependence on the automobile, large lot residential development and strip commercial development. Although there is no uniform definition of the term ‘urban sprawl’, the following could be considered as the basic elements of urban sprawl:

- Separation of uses: residential, recreational and other uses are disconnected within separate zones of development. Thus everyday activities are difficult to reach on foot, or using bikes or public transportation, and as a result different social and age groups can not mingle.
- Disconnection of streets: routes within zones are blocked and disconnected by numerous cul-de-sacs. This makes walking, biking, and using public transportation less convenient, and almost all trips are done using private vehicles through automobile-dominated streets that are dangerous, ugly and congested.
The expansion of Cairo had taken the pattern of urban sprawl, as building grew from existing districts towards the agricultural fringes, and later the desert fringes. The construction of the ring road in 1984 encouraged such urban pattern, especially that during the 1980s, Cairo was witnessing a gradual improvement of its infrastructure (Sims, 2010). The urban sprawl provided housing for large segments of the society, and just as the residents of the informal areas found advantages in their settings, the residents of the urban sprawl acknowledge a number of advantages such as the good condition of the new structures, the relative spaciousness of their units. On the other hand, they suffer from the lack of commercial, social and cultural facilities and the absence of green and open spaces, in addition to the daily commute to the center and other parts of Cairo, which is done by using a number of informal transportation means.

**D. Gated communities:**

The rapid spread of exclusive urban communities could be regarded as one of the defining characteristics of urbanization in the last quarter of the twentieth century, and “Gated Communities” have represented the typical patterns of this development (Webster, 2001). In general, a “Gated Community”: is an urban settlement surrounded by walls with several entrances, these entrances are controlled by gates and guarded by security agents. The access to these settlements is strictly reserved, generally, to the residents and their visitors. These settlements are usually equipped by big shopping centres and malls, cinemas, recreational facilities, parks, swimming pools, beaches, artificial lakes, etc.)

The 1980s saw the proliferation of gated communities built around golf courses that were designed primarily for exclusivity, prestige and leisure. Since the late 1980s, gated communities have become common in developed and developing countries (Blakely et al, 1998). The phenomenon of gated communities appeared in Egypt in the 1980s as a consequence of socio-cultural and economic changes related to globalization and economic restructuring (Denis, 2006). The first examples of gated communities appeared as secondary houses in the coastal zones, mainly along the Mediterranean coast west of Alexandria. Then, in the mid-1990s, they evolved to accommodate residential uses, mainly around the Greater Cairo Region. Over the last three decades, the construction of exclusive gated communities has increased gradually, primarily on the outskirts, where large parcels of affordable land are available.

The Egyptian gated communities resemble the American ones built around recreational areas and golf courses and in the sense that they are locally acknowledged and consequently marketed “as the cutting edge of a post-metropolitan lifestyle” (Denis, 2006). They represent social exclusiveness and prestigious suburban lifestyle commonly achieved through unique architectural character, security, distinctive leisure amenities, and
sometimes also service facilities. In contrast to living in a crowded and chaotic city such as Cairo, a gated community has an irresistible allure by those who can afford it.

Gated communities provide the residents with more variations in housing typologies, green spaces, and a healthier environment than the old congested neighborhoods but lack the required commercial, social and cultural facilities and lack a distinctive character. Most of the residents of these gated communities are of the same income group. Residential areas are designed with modest densities that do not exceed 50-70 persons per hectare, as almost 60% of the area is devoted to open spaces, green areas and wide streets (Sims, 2014). It is noteworthy that some of the housing units in the gated communities are used as a kind of investment, which tends to be more profitable and more secure than other forms of investment available in Egypt. Accordingly, some of the units are left vacant and this leads to a reduction in the already low density. The main disadvantage of living in such gated communities is the need to commute to work for long hours on daily basis.

**Inspiration from the historic cities of the Arab hot arid region**

The historic cities, took their shapes as a result of accumulated experiences over a long period of time and the outcome of many trials of the inhabitants. These settlements which were shaped by numerous socio-economic, political and cultural factors, succeeded in fulfilling the various needs of their inhabitants for centuries, while depending on the available resources and responding to the environmental circumstances. However the hot arid environment was one of the main factors in forming the cities’ physical form, a compact and introverted nature of the settlements and their components. Courtyard buildings were clustered to provide shade and to create cooler microclimates, thus creating a distinctive urban form, described by Costa and Noble as “an almost continuous low-rise, high density settlement”(Costa et al, 1982). The courtyards provided natural light and ventilation and allowed wall-to-wall construction of adjacent buildings, thus eliminated wasted spaces between buildings as well as heat gain or loss, in addition to preserving the privacy of each dwelling. The dwellings and the settlements grew in an organic way, in a process of adding one unit to another without a preconceived plan (Ragette, 2003). The environment also defined the public realm of the settlements which was composed of narrow streets with a very few open spaces that were limited in size, as the main concern was to protect the passersby and the users of the public spaces from direct sunrays and dusty winds.

The heart of the settlement contained the main mosque, the market and other civic buildings serving the inhabitants. The gathering of these public buildings formed an interlocking urban form,( usually an irregularly shaped small piazza) , and the spaces around them were considered the public spaces of the town, where the different inhabitants of the neighbourhoods gathered and met. Streets branched out from the centre, to the different residential clusters, through lanes and narrow alleyways that finally ended by dead-end streets. The irregular street networks composed of winding, narrow, dead-end alley, provided shade, protected from sand storms and determined public, semi public and private spheres. As the city grew, new residential quarters might extend further away from the centre. These quarters would be linked to the centre by the main streets, and the same system of street hierarchy will be applied in these new quarters, as the main street will branch into access roads, alleys and end by cul-de-sac.

**What are the design principles of the historic cities of the Arab hot arid region?**
The historic cities of the Arab hot arid region are characterized by a number of design principles, whose validity have been tested through centuries of modifications and accumulation of the inhabitants’ experiences. Among the various design principles that helped in shaping the historic cities, are:

- Compactness of urban form
- High density
- Mixed land use
- Hierarchy of circulation networks
- Considering and adapting to the environmental conditions
- Using several housing typologies
- Creating and maintaining an architectural character

**Could the “Compactness” principle be applied in contemporary designs?**

It could be stated that the compactness of the urban traditional settlements in the hot arid regions, and the adoption of the courtyard house as a typical building typology, resulted in a number of socio-economic and environmental advantages. Such as the clear distinction between private, semi-private and public spaces, the proximity of different religious, social and commercial activities to the residential areas and the creation of a milder microclimate by reducing the wall areas exposed to solar radiation and increasing the areas of shaded surfaces. These advantages could still be achieved in contemporary residential developments.

By looking at the historic cities as models, it could be deduced that adopting a similar compact urban fabric would ensure the optimum use of land, reduce the infrastructure costs, and also decrease the dependency on vehicular movement, thus giving the maximum efficiency with the limited available resources.

**Could the “High Density” principle be applied in contemporary designs?**

What has been the norm in almost all the traditional settlements of the hot arid region for millennia was recently recommended as a principle of creating sustainable neighbourhoods. In a United Nations Habitat report, entitled “A new strategy of sustainable neighbourhood planning: Five Principles”, high density, defined as a concentration of people and their activities, was recommended in urban growth to prevent urban sprawl, promote sustainable urban extension and maximize land efficiency. The report listed the following economic, social and environmental benefits:

- Slows down urban sprawl because high-density neighbourhoods can accommodate more people per area.
- Reduces public service costs, costs of land acquisitions and site infrastructure
- Reduces car dependency and parking demand, and increases support for public transport.
- Increases energy efficiency and decreases pollution

**Could the “Mixed Land-use” principle be applied in contemporary designs?**

The principle of mixed land use, which has been adopted in traditional settlements, was recently reintroduced to help in creating sustainable neighbourhoods and address the current urbanization challenges. In a United Nations Habitat report, entitled “A new strategy of sustainable neighbourhood planning: Five Principles”, the application of mixed land-use concept is considered to be a strong factor in creating local jobs, promoting the local economy, reducing car dependency, encouraging pedestrian and cyclist traffic, reducing
landscape fragmentation, providing closer public services and supporting mixed communities. Mixed land-use requires some combination of residential, commercial, industrial, educational, health, spiritual, civic and residential uses, to create the opportunity of living and working within the same urban environment, something which has been the norm almost everywhere in the world.

Learning from the traditional settlements and understanding how the principle of mixed land use was applied, results in gathering the necessary facilities in the centre of the neighbourhood while still providing other minor facilities zones, near the edges. This would respond to the daily needs of the inhabitants, and create a livable community.

Could the “Hierarchy of Circulation Network” principle be applied in contemporary designs?

In search of solutions to the current urban problems and most importantly urban sprawl, pedestrian friendly streets are being promoted and street networks that are designed only for vehicles and public transportation are being revised. The traditional hierarchal street network with arterial routes and local streets based on traffic speed differences is being recently recommended to promote walkability. Such street network would shape the urban fabric, by affecting the pattern of clusters, building blocks and open spaces, yet it would also, bring people back into the public space, reduce congestion and boost local economy and interactions. It is impossible to ignore vehicles or public transportation while designing a new neighbourhood, as creating a replica of an old settlement is neither a logical nor a possible option. However there should be a balance between the dependence on vehicles and the possibility to walk to nearby facilities.

Could the “Adaptation to the Environmental Conditions” principle be applied in contemporary designs?

Responding to the local environmental conditions became a crucial aspect, and now environmental studies in architecture and urbanism could be considered separate specializations. Although, the adapting to the environmental conditions might seem to be beyond the scope of this paper, however it is important to deduce some aspects of what have been previously considered in the historic cities. For example, the proper orientation of the buildings and the use of inner courtyards, which have been effective in improving the microclimate of these cities, are simple factors that must be respected and could be easily incorporated in contemporary designs. Courtyards could be easily reintroduced in the current architectural language to create a microclimate within a harsh climate, and to respond to the needs of convenience.

Could the “Adoption of several housing typologies” principle be applied in contemporary designs?

The use of several housing typologies responds to the various needs of different age and income group that comprise any settlement. Such variety is reflected not only on the economic aspects of a neighbourhood, but also on its aesthetics, as the variety in housing typologies is translated in a variety of masses, forms and architectural details. Unfortunately courtyard houses as a contemporary form have almost disappeared from urban areas in the hot arid region. The evolution of the courtyard house in Egypt, as an example, was disrupted at the beginning of the 19th century, and by the early 20th century, and due to further socio-economic changes the apartment buildings with light well courts became, and continue to be, the standard residential building type in Cairo and almost all the cities of the region. In these buildings most of the spaces whenever possible had
openings to the streets and the kitchen and bathroom were clustered around a tiny light well. The perception of the apartment block as the sole housing typology, in addition to other socio-economic and cultural factors, stopped the attempts to adopt the traditional housing typologies, such as the courtyard house and the rab’ (residential units gathered around a common courtyard) to the contemporary urban fabric.

The innovative designs reintroducing the traditional housing typologies, such as the courtyard houses and the rab’ in a contemporary urban setting, in addition to their socio-economic, aesthetic and cultural benefits encourage architects to provide more creative typologies to the limited ones prevailing nowadays.

**Could the “Creation of an architectural character” principle be applied in contemporary designs?**

The need to revive or preserve the architectural character of a specific region does not mean relying on images that reduce the past to pastiche, but to find solutions to current problems. However using decorative patterns and motifs is an important aspect in re-establishing the character and identity of the place, reviving local crafts and accordingly improving the local economy.

Starting from the second half of the twentieth century almost all of the traditional principles that shaped the built environment of the hot arid region, were abandoned in favour of “modern” western principles. Such imported principles, which were, in most cases, inappropriate to the cultural, environmental, and socio-economic circumstances of the region resulted in a built form that lacked many of the advantages of the previous one. The contemporary housing models prevailing in the region, suffer from a number of defects, most importantly, these models ignore the needs of the inhabitants and the specific climatic conditions. For example, the setbacks dictated by the planners and municipalities resulted in wasting a considerable area of the plot, which is environmentally harmful, as they expose all the walls of the house to solar radiation. Another example could be the duplication of the Western or European concept of a balcony in a multi-storey apartment building did not respond to the needs for privacy and climatic requirements. Further research and design initiative are needed to study and analyse the architectural language of the region, and develop various elements and patterns that respond to the contemporary needs while reflecting the social and cultural identity.

**A proposal to design a residential neighbourhood in New Cairo**

This is a proposal to create an integrated urban community that brings together a social structure that has been fragmented, in Egypt, and most of the Arab hot arid region. Creating a holistic urban environment could be achieved by building a high –density, mixed-use urban neighbourhood in New Cairo, as an example of building contemporary residential developments in the region. Figure1.

**The Site of the project**

An undeveloped parcel of land within Al Rehab, which is a part of New Cairo, was chosen for the project. New Cairo is a city covering an area of about 70,000 acres on the south-eastern edge of Cairo. New Cairo enjoys a good standard of infrastructure and road networks, mainly because of the relative flat topography of the site. It is connected to the Eastern parts of Cairo and Cairo International Airport through the ring road. It is also connected to the highways leading to Suez, Sinai and the Red Sea.
Al Rehab emerged as one of the gated communities in the Greater Cairo Region (GCR), which evolved to accommodate residential uses. The idea of selecting a part of Al Rehab city was to show an alternative way of building to what has been already built in the same context. The circulation network and land divisions that are applied to New Cairo and other parts in the Greater Cairo region lead to the creation of gated communities or sprawl. Accordingly this proposal is an attempt to create a different urban and architectural product within the same context.

![Figure 1. Land use plan of the proposed neighbourhood.](image)

**Design principles adopted in the design**

*The compactness of form:*

The current design approach in residential developments is to calculate the carrying capacity of a plot, divide this number among several flat blocks, assigning a standard percentage of the plot to circulation network and the rest of the area is considered to be green spaces. The greater the percentage of the green areas within the neighbourhood the
better, as green areas are used as major marketing tools for the gated communities. However such configuration usually leads to the creation of isolated structures surrounded by adjacent structures, thus the residents still don’t enjoy the required sense of privacy in spite of a reasonable percentage of land allocated to the green spaces. Moreover the green spaces are usually dispersed within the buildings, and not identified spaces; therefore they are seldom used by the residents as gardens or playing areas.

Learning from the traditional urbanism, and acknowledging the importance of creating a compact urban form in such a harsh desert context, the design creates compact clusters containing semi private open spaces. In addition to the environmental advantages of the compactness of the built form, such configuration enables the residents to reach a variety of commercial, cultural, religious and educational facilities within walking distances, and this kind of accessibility to a variety of facilities is rarely achieved in gated communities.

*Mixed land uses:*

Whether residing in a gated community or within urban sprawl, a resident will depend on a vehicle to reach any of the commercial, religious, recreational or educational facilities needed. Malls, large mosques, school complexes and office buildings appeared along the main high ways in relatively isolated locations from the residential units. This results in a lifestyle that forces the residents to spend most of their time in their vehicles and minimizes their interaction with their neighbourhood. Accordingly, the residents of gated communities have lost one of the major advantages of living in the conventional neighbourhoods, where they were able to reach most of the required facilities on foot at ease.

In an attempt to revive the useful combination of uses and facilities among the residential units, the main services needed (the main mosque, school) are allocated in a central location that could be reached easily by most of the residents. However gathering all the services at one place would have led to congestion and noise that would harm the adjacent residential units and at the same time would mean that the rest of the neighbourhood is composed of residential units only. Thus the facilities were spread across the neighbourhood to ensure that almost each resident can reach the main facilities at ease (local mosque, nursery, grocery store,…). Parking lots are provided near the various facilities however, the design aims to encourage most of the residents living around the main facilities within the centre of the neighbourhood to start using other means of transportation rather than private vehicles.

*The circulation network:*

Studying the context of the site was important to understand how the neighbourhood could be linked to the adjacent and nearby neighbourhoods, and how many entry points would the neighbourhood have. The design of the inner circulation network maintained a specific hierarchy that ranged from collective, shared and local roads, to respond to the needs of the residents in using different modes of transportation and also to encourage cycling and walking, in addition to ensuring that passers-by will not use the neighbourhoods streets as short cuts leading to unneeded congestion.

The aim of the design of the circulation network was to ensure that vehicular routes were spread almost all over the neighbourhood without compromising the presence of pedestrian routes and the sense of serenity within the residential clusters. The circulation network design created an inner loop within the neighbourhood, thus creating a number of residential clusters surrounding a core that contains the main commercial and cultural
facilities. The circulation network could be seen as two inseparable layers, a vehicular network and a pedestrian one. These two layers complement each other and whenever they intersect, a safe and pedestrian friendly zone is created to ensure that the pedestrian routes are uninterrupted. Creating a variety of spaces within the neighbourhood was an important aspect that ensured a lively social life in the conventional neighbourhoods and seemed to be missing in most of the gated communities. Thus a variety of open spaces was adopted in the design where, public and semi public squares varied in size and composition to fulfil the different needs of the residents, from congregational prayers, to outdoor dining, kids play areas and even small social gatherings. Also semi private spaces were considered within the residential clusters, so that the residents of a group of houses could enjoy a common green area or parking spaces without any interference from outsiders.

**Housing Typologies:**

The historic cities of the Arab hot arid region provided shelter, work and education for everyone. Different age and income groups lived and interacted together without any difficulty. The variation of the income groups was reflected in providing a variety of housing typologies, especially that the majority of the gated communities do not consider this aspect. The design adopted three main housing typologies, the courtyard house, the flat blocks and the traditional rab’, which is a group of residential units gathered around a courtyard. These three typologies, with the variations in their areas provide housing to different income and age groups. Moreover the rab’ provides commercial and office spaces in addition to small residential units that could be easily rented to small families or university students.

**Environmental considerations:**

The ever-increasing demands on electricity for cooling and even heating in the current residential units reflect how the environmental context has been neglected. Specially that the new building materials used like concrete and fired bricks are poorer in thermal insulation if compared to the stone blocks or even the thick brick bearing walls. It is a fact that due to economical reasons, the nature and thickness of the building materials do not provide proper thermal insulation, resulting in negative implications. Therefore it is important to make use of other design aspects that could respond to the climate in a better way. The clustering of the buildings plays an important role in shading adjacent buildings and open spaces. Also the use of courtyards, whether in rab’ or the small private ones help in regulating the microclimate of the houses and creating livable outdoor spaces. In addition to the use of buildings massing, courtyards and shading other low-tech devices and design considerations could be added to improve the micro climate of the neighbourhood and the environmental performance of its buildings, such as the use of cavity walls, the location and width of the openings and wind catchers. Further research and collaboration with specialists in other disciplines is needed to be able to improve the microclimate of residential neighbourhoods in the hot arid region.

**Landscape:**

In recent years, the promoters of the gated communities reduced the concept of landscape design to vegetation and green patches. However landscape design is a more comprehensive scheme than just allocating some vegetation and green spaces within a neighbourhood. In the hot arid climate communal green patches are subject to neglect and deterioration, especially when considering the high cost of irrigation. Thus the landscape
design of the neighbourhood depended on providing a variety of open spaces that range from public, semi public, semi private and private. In these spaces local species that could withstand the climate will be used sensibly among other hard scape materials. This will ensure that there are green semi public and public spaces that are enjoyed and used by the residents and not only added to reflect a fancy ambience. The landscape design also will include street furniture like lamps, canopies, shading devices and benches in addition to flooring materials. The economical and environmental factors will be considered to ensure that the materials used are affordable and appropriate to the context.

Concluding Remarks:
The fragmentation of Cairo into urban zones led to an obvious fragmentation of the society. Therefore the proposed design aims at creating an integrated urban community that could provide a better physical and social environment than what is currently offered in Cairo. The proposed design is an attempt to apply the principles of the traditional urbanism of the region within a real context of Cairo. The main aim was to provide a more appropriate alternative to what is being offered, putting into consideration the socio-economical, environmental and aesthetic values. Such proposal aims at reintroducing and evaluating the urban principles and not to create specific forms. Accordingly as long as the principles are considered within the design, the forms could change from a region to the other, and depending to the context and the budget of each neighbourhood.

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The Interrelationship Between Urban Mobility, and Urban Form

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Abstract: Throughout human history, urban development of cities has become one of the most important phenomena that accompany the general development of human life on the planet. From this perspective, it is important for the urbanists to constantly revisit, review, and develop the principles of urban development in an innovative way. Neighbourhoods are the main ingredient of the city. Developing existing neighbourhoods and building new ones requires great care because of its direct impact on city form in terms of sustainability. As reducing greenhouse gas emission and rationalizing energy consumption are objectives of sustainable development and new trends in urban design depending on strategies of sustainable mobility and transportation systems which considered as governing factors to achieve those goals. Reducing private car reliance on travelling within the neighbourhood is a key strategy. The paper aims to understand the patterns of mobility within modern neighbourhood to enable urbanists to develop an adjacent shape commensurate with sustainability requirements for through documenting and analysing the interrelationship between patterns of mobility, transportation means and the urban form of New-Cairo's neighbourhoods. In order to establish a clear understanding of the behaviour of residents in relation to patterns of mobility to assess the opportunities that urban form can provide to reduce reliance on the private car and enhance relying on green transportation such as walking, and cycling. The paper begins with an overview of the concept of urban mobility. The paper followed the post-positivist paradigm (quantitative paradigm) with correlational strategy and multiple case studies with literal replication as research design. Primary data obtained through questionnaire prepared for a representative group of middle-class and upper-middle-class who chosen at random from inhabitants of New-Cairo. The paper confirms that urban design has its direct impact on mobility patterns and transportation. The conscious urban design has its direct impact on sustainability.

Keywords: Urban Form, Urban Mobility, Pattern of Mobility, Sustainable Neighbourhood, Sustainable Transportation

Introduction to Urban Mobility

Urban mobility is the whole of trips generated daily by the inhabitants of a city, and the methods and conditions associated with such trips (modes of transport selected, length of trip, time spent in transport, etc.) (Foth, 2009). Also, Leonardo Kubitschek (Brazilian Senior Consultant of Marketing & Strategy) describes urban mobility as it is the way people move in the city most common and important move is from home-work, work-home. As urban mobility is a term that refers to how and when people move in cities, it becomes an important indicator for measuring the quality of urban life, so therefore it was natural to face many challenges at the environmental, economic and social level. The traffic gridlocks experienced on city roads and highways have been the basis for the development of most urban transportation strategies and policies. The solution prescribed in most of these has been to build more infrastructures for cars, with a limited number of cities improving public transport systems in a sustainable manner. However, the transportation sector is also responsible for a number of other challenges that do not necessarily get solved by the construction of new infrastructure. This paper focuses on the interrelationship between patterns of urban mobility, transportation means, and neighbourhoods urban form characteristics. In order to
assess the opportunities that urban form can provide to reduce reliance on the private car and enhance relying on public, and green transportation. But, does the built environment affect how often and how far people drive or walk or when they will take the bus or the train? If so, how? The answer to the first question would seem to be, beyond a doubt, yes. Especially in today’s car-dominated urban landscape, one has difficulty imagining, let alone arguing, that travel patterns would not change if cities were less decentralized, or if more stores, jobs, and schools were within walking distance of home, or if parking and highways were nowhere to be found. Travel would certainly be different if these things were different. Although the answer may seem obvious—how could street layouts and the density of development possibly not matter? (Crane, 2000). However, urban planning and design for these cities and others in the medium and high-income brackets is crucial to reduce distances and increase accessibility to enhancing sustainable urban transport solutions. If city residents can achieve access through more efficient travel (online shopping or car-sharing), or by travelling shorter distances, this will contribute to reducing some of the challenges currently posed by urban transport. Thus, urban design should focus on how to bring people and places together, by creating cities that focus on accessibility, rather than simply increasing the length of urban transport infrastructure or increasing the movement of people or goods (UN-Habitat, 2013).

**Urban Mobility through Transportation Means, Congestion, and Pollution**

If we were to imagine a person from another planet landing on one of the streets of downtown Cairo at any hour of the day, what could he possibly think of this thing that we call the private car? Let us suppose that no one had told him anything about it, that for instance, we consider it a quick, convenient, and economical means of transportation; would this occur to him as he saw these thousands of cars parked on both sides of the road, or proceeding at the pace of a turtle through narrow streets, moving forward for a few moments and then stopping again, each one occupied by one person or two when it has space for four or five? (Amin, 2000). From the previous paragraph, it is clear that what is happening in Cairo is no different from what is happening in many cities around the world. The growth of private motorized transport during the twentieth century had major impacts on the growth and development of cities all over the world. In 2010 there were 825 million passenger cars globally. Of these, close to 70 per cent were in developed countries, whilst only 30 percent were in developing countries (see Figure 1) (UN-Habitat, 2013).

![Figure 1. Total stock of motor vehicles, OECD and non-OECD countries Source: (IEA, 2009).](image-url)
According to the report issued by CAPMAS (Egypt’s Central Agency for Public Mobilization and Statistics), Cairo Governorate has 2.3 million licensed vehicles (25.1 percent) of total number of cars in Egypt (Ahram Online, 2017). Traffic congestion is an undesirable by-product of widespread urban mobility in cities worldwide, and a major factor in restricting access in cities. It has extensive impacts on the urban quality of life, consumption of fossil fuels, air pollution, and economic growth and prosperity (UN-Habitat, 2013). According to statement by the head of the Public Transport Authority in December 2017, Egypt loses 187 billion pounds annually due to traffic congestion. In addition, in 2016 the Minister of Environment stated that the air pollution ratio in Cairo exceeds international indicators 7 times. Also according to German Federal Ministry for Economic Cooperation and Development (BMZ) urban mobility report in 2016 traffic jams cost Cairo USD 8 billion a year the equivalent of 4 percent of Egypt's economic output (BMZ, 2016).

Urban Mobility, and Urban Form

Heightened concerns over climate change, rising gasoline prices, traffic congestion and social exclusion have sparked renewed interest in exploring the link between mobility and urban form. Despite this, most cities, particularly in developing countries and emerging economies, continue to prioritize motorized transport and related urban infrastructure. A reinvigorated notion of urban planning, solid institutions and governing structures is therefore required. Differences in the urban form – emerging either from a haphazard process of locating settlements and activities, or from strategically planned intervention – can create big differences in mobility systems. Key considerations include the pattern of street arrangement, the length of blocks, and the relationship of buildings to pathways, stations and central places (UN-Habitat, 2013). Mobility variables usually considered are: trip length, number of trips, modal shares and the number of kilometres travelled per capita, which is a rough estimation of gasoline consumption per capita (Pouyanne, 2010). Urban form is usually measured through the “3D’s”: Density, Diversity (of land use), and Design (Cervero & Kockelman, 1997).

Density

The influence of density on travel patterns is now well-known. We have noticed above how convergent the results are, at an inter-urban scale as much as at an interurban scale (Pouyanne, 2010). The Newman and Kenworthy (1989)’s curve has been verified: residential density and employment density have a negative influence on vehicle-miles travelled (see Figure 2) (Newman & Kenworthy, 1989).

Diversity of Land Use

The simplest measure of diversity is given by R. Camagni et al. (2002) in their study on the metropolitan area of Milan (Italy). Two functions are considered: to live and to work. Then land use mix is the jobs-housing ratio. The jobs-housing balance influences negatively the ecological impact of mobility, which indicates “a growing impact with an increase of the residential content of a zone” (Camagni, et al., 2002). Travel behaviours may not be the same according to the purpose of the trip: homework trips are usually distinguished from commercial or leisure trips. As a consequence, some studies make a difference between retail and others jobs; then, the measure of diversity is based on the sectoral distribution of jobs. For example, D. Chatman (2003) tries to explain mileage travelled for commercial purpose by the proportion of retail jobs in the area, but he does not find any significant relationship (Pouyanne, 2010).
Some authors have pointed out the influence of urban design on travel patterns. For example, M. Boarnett and R. Crane (2001) show that a grid-shaped street pattern raises the modal share of the automobile for non-work trips. At the contrary, the number of culs-de-sac is inversely correlated to walking (Rajamani, et al., 2003). Some other urban design characteristics, such as parking disponibility (Naess & Sandberg, 1996) or the density of bicycle paths (Cervero & Kockelman, 1997), also influence travel patterns. Studies presented here bring a comprehensive view of the urban form – travel patterns interaction. However, some methodological issues related to this question must be stressed. They constitute a basis to formulate an original statistical method (Pouyanne, 2010). At the micro level, much is to be gained from advancing the model of ‘complete streets’; an acknowledgement that streets serve numerous purposes, not just moving cars and trucks (UN-Habitat, 2013).

**New Cairo as Research’s Context**

Many countries followed the policy of establishing new cities in the aim of redistribution of the population or to be as a nucleus that assists in encouraging the economic activity of a certain region or to be a new capital. Many cities were being developed according to development stages. New Cairo is one of the second generation cities. It is characterized by its distinctive developed location. It has been developed as a result of the economy and investment politics of the Egyptian government at this time, which made it the focus of real estate investment. However, this resulted in negative influences on the sustainability (Hafez, 2015). New Cairo city lies in the eastern area of Cairo on the ring road and located in the area between Cairo-Suez desert road and Cairo El Ain El Sokhna desert road. Its area reached 70 thousand feddan (see Figure 3) (Hafez, 2015).
Figure 3. New Cairo land use map (NUCA, 2017)

Methodology

This research paper aims at documenting, and analysing the interrelationship between patterns of urban mobility, transportation means, and urban form characteristics within New-Cairo’s neighbourhoods. In order to establish a clear understanding of the behaviour of urban residents in relation to patterns of mobility to assess the opportunities that urban form can provide to reduce reliance on the private car and enhance relying on green transportation such as walking, and cycling within New-Cairo’s neighbourhoods. The paper followed the post-positivist paradigm (quantitative paradigm) with correlational strategy and multiple case studies with literal replication as research design. The neighbourhoods of New Cairo which were chosen as the cases of this research study were chosen in order to corroborate each other in literal replication. Beside data related to case-study, primary data obtained through questionnaire prepared for study sample. The study sample consists of a representative group of 100 Participants, that exemplifies the families and individuals of middle-class and upper-middle-class. This representative group of people was chosen at random from the inhabitants of neighbourhoods in New Cairo City. Then according to the analysis of New-Cairo’s neighbourhoods urban form characteristics in the light of the information collected from the field study, this paper confirms the interrelationship between mobility patterns and urban form as an approach towards a sustainable neighbourhood with urban characteristics enhance relying on environmentally friendly transportation for less pollution, better health and a more sustainable society.

Questionnaire Design

This questionnaire begins with a brief introduction for those who are about to fill in the questionnaire. In order to understand the main purpose of this questionnaire. And also clarify the definition of the main concept in this research which is urban mobility. Then, the questionnaire is divided into four main parts.
**Personal Profile**

This part of the questionnaire includes the participant's personal data in order to facilitate the analysis process of data and relate it to the general personal situation of participants to obtain more reflective results.

**Commuting to Work**

Urban work-trips in many parts of the world have received a considerable theoretical and empirical treatment in the literature (Okoko, 2008). This part focuses on the most frequent daily travel that represent the majority of daily routine trips to many people. Questions cover many aspects of this pattern of mobility. Also covers choices of transportation means and the reasons for those choices.

**Patterns of Mobility, and Urban Life**

This part deals with patterns of mobility that are most influential in the lifestyle of families and individuals of middle-class and upper-middle-class. Also covers the choice of means of transportation and the repetition of every pattern of those urban mobility patterns. And investigates the relationship between the participants and the surrounding urban environment at the neighbourhood scale. And how the urban form characteristics can affect their pattern of mobility and also affect their choices of transportation means.

**Transportation Means Profile**

This part of the questionnaire focuses on transportation means. It is divided into two sections; the first section covers the private car. The second section focuses on green transportation. And what are the urban obstacles that hinder the ability of reliance on it? And also investigates the willingness of participants to rely on green transportation.

**Review, and Analysing the Information Coming from the Questionnaire.**

These kind of information are very useful for travel studies because so many factors are involved. Where people want to go and how they plan to get there depends on their resources; the transportation network in place; their access to a car, bus, or commuter rail system; the needs, demands, and desires of their families; their demand for the goods that travel can access; the price of gasoline; bus fares; and so on. Many things appear to matter, and multivariate methods are well suited to the analysis of such situations (Crane, 2000). Descriptive statistics are done with IBM SPSS Statistics version 23. The study sample distributed equally (50% female, and 50% male) covers age groups as shown in figure (see Figure 4). But on the level of employment status, 50% of the participants are full-time employed, 23.3% part-time employed, 13.3% freelancer, 6.7% homemaker (Housewife), and 6.7% self-employed. But on the level of social responsibilities, 40% of them are individual when 60% are responsible for families. New-Cairo was established with a Presidential decree number (191) for the year 2000 the eastern parts were annexed to the cordon of the city, leasing it to some private and public companies (Hafez, 2015). Since it is clear that the age of New-Cairo is between 15 and 18 years, therefore the main strength of the population is the internal migration. And by asking the participants in the questionnaire why they moved to New Cairo, 53.3% refer this to the urban environment, 36.7% refer this to social issues when 6.7% refer this to their workplace and only 3.3% refer this to other reasons. From this, it is clear that many of those who moved to New-Cairo had high expectations about the urban environment. The workplace of 46.7% of participants located in New-Cairo while the other
46.7% of their workplace is outside New-Cairo and only 6.7% doesn't work. 71.4% of those participants who had their workplace located in New-Cairo evaluated their overall commuting experience as average while 14.3% evaluated it above average and 14.3% evaluated their experience as excellent. And they travel distances from 3km to 20km in their daily work commute travel. Those trips take them from 5 minutes to 20 minutes. While the other 42.9% of the participants who had their workplace located outside New-Cairo evaluated their experience as average while the other 57.1% evaluated their experience as below average. They travel distances from 20km to 90km in their daily work commute travel. Those trips take them from 30 minutes to 120 minutes. Thus, there is an inverse relationship between the satisfaction of inhabitants with the experience of urban mobility and the length of the distance they travel in the day-to-day work journey. 82.1% of participants rely on their private cars in commuting to work, while 10.7% of them uses a private driver to their own cars. 7.1% rely on firm's buses, while 7.1% rely on taxi and 3.6% public transportation. And by asking the participants to mention the main reason for choosing this mode of transportation in commuting to work. the participants who use public transportation choses (Cheapest), while 75% of the participants who use firm's buses, and taxi chose (Lack of Alternatives) and the other 25% chose (Reliability). And for those who use private cars, 34.8% of them chose (Reliability) also while 26.1% chose (Personal Safety), while 21.7% chose (Lack of Alternatives), and 17.4% chose (Other Commitments).

On the economic level, the participants who use a private car in commuting to work, the travel cost them from 150 to 1600 Egyptian pounds while those participants who use other transportation modes the travel cost them from 120 to 1000 Egyptian pounds. Despite varying in evaluations of urban mobility experience, 82.1% of the participants agree that the mode of transportation they choose provides them with the necessary psychological and physical comfort. Despite the increased demand for using private cars in general, but by asking the participants the modes of transportation they hope to use for the commute to work. 7.1% hope to use a private car, 17.8% car-sharing and carpooling mobile-apps, 35.7% public transportation (underground, and over-ground tram), while 14.3% prefer walking, and 21.4% prefer cycling (see Figure 5). Then by asking about the obstacles preventing from using this mode of transportation now. 39.3% not available, 10.7% not safe, 21.4% no special lane.
for bicycles and walking, 3.6% financial issues, 3.6% social issues, and 21.4% not Reliable. From the previous percentages, it is important to invest in urban infrastructure that supports sustainable transport modes and the construction of reliable public transport networks. The participants showed a desire to use green transportation modes, which they can’t use because of not having a safe urban place for it (no special lane for bicycles and walking) and here comes the role urban development. 70% of all participants agree that the streets’ design in New-Cairo affects their choices of modes of transportation. When the participants asked to describe a street that enhances their sense of safety, 70% chose mixed-use street (combines residential and commercial activity), 13.3% chose a single-use street, 16.7% pedestrian street. Sketch was presented to the participants and the following question was asked (would you prefer the design of main streets in New-Cairo to be like?) (see Figure 6).

**Figure 5.** Source: Author’s Field Survey, 2018.

Then they were asked to choose one of the following answers (1) A street that provides more mixed-use lanes and pavement for pedestrians. (2) A street that provides separate lanes for every different means of transportation and specific places for street activities. only 16.7% chose street (1), while the other 83.3% chose street (2). After asking the questions for the design of the streets came the role of focusing on neighbourhood local service area. 33.3% visits the local service weekly. 16.7% three times a week, 16.7% twice a week, 16.7% every day, 10% five times a week, while only 6.7% don’t go. About those who go 70% use a private car, 16.7% walk, 10% use taxi, while 3.3% use bicycle. 73.6% of them refer their choices to the lack of alternatives. Then by asking them about kind of service they think should be added to this service area, 33.3% chose gym, 30% chose sports playgrounds, 16.7% kindergarten, 13.3% health unit. Kindergarten, and health units are supposed to be included in the local service area of any neighbourhood according to New-Cairo urban design regulations but they are not implemented until population densities are high due to economic conditions. But services like gym and sports playgrounds which had almost 60% are not included. and this high percent shows how inhabitants from middle-class and upper-middle-class care about sports activity. From here had to be questions about it, in order to find out the importance of that pattern of mobility. 23.2% hit the gym every day, 6.7% five times a week, 16.7% three times a week, 16.7% twice a week, 16.7% weekly. That’s mean around 80% of participant consider this pattern an important part of the weekly mobility routine. 60% use a private car, 6.7% use taxi,
while 23.3% walks, and 10% use bicycle. About the local garden within the residential block. Only 73.3% of participants have a garden within their residential block. 66.6% of them don't interact with this garden, they refer this to a lot of reasons such as (not safe, no proper lighting, not clean). 96.7% of all participants agree with the idea of changing the use of this garden. 43.3% see it as improved gathering space for family, 33% jogging track, 3.3% sports playgrounds, 20% play area for children when no one sees it as (car-parking yard).

Figure 6. Sustainable street sketch, Source: (NACTO, 2016).

**Transportation Means**

86% of participants own a private car. Those private cars cut off trips per week between 6 trips to 30 trips, and coats their owners per month between 600 to 2500 Egyptian pounds. By asking the participants about the number of people normally travel in their car, 70% chose one person only, 26.6% chose two persons, and 3.3% chose three persons. 56% of participants are not interested in car-sharing (lift-sharing or carpooling). Although 86% of participants own a private car, only 30% of participants own a bicycle. By asking the participants if they do any travelling by walking, 46.7% said yes, 53.3% said no. By asking the participants if they would be encouraged to have an active commute (walking or cycling) if the following work was undertaken in your organization such as Lockers and shower areas provided / increased / Improved, and cycle parking increased then, 63.3% said yes. Also if they would be interested in any of the following initiatives to promote walking or cycling. 23.3% walking route marked out in the local area, 60% special lanes for bicycles and walking, 16.7% nothing. Also, 93.3% are agreeing with the idea of increasing the number of pedestrian streets, and pedestrian piazzas in New-Cairo (Pedestrianisation).
New-Cairo's Neighbourhoods Urban Form Analysis

As is clear from the information collected from the questionnaire and what is evident in Maps in Figure 3, and 7 at the level of New Cairo as a city and at the level of its neighbourhoods. The streets layouts are directed to serve different kinds of motorized transportation means. While a lot of the participants who have jobs are willing to rely on walking and cycling for their daily work-trip only if appropriate special lane for bicycles and walking are provided in the streets to enhance their sense of security. On the other hand, the majority chose to have streets that provide separate lanes for every different means of transportation and specific places for street activities, and also, admit that having this kind of streets in New-Cairo will encourage them to rely on walking and cycling in a larger way (see Figure 6). Cervero and Gorham suggested that street layouts do influence commuting behaviour (Cervero & Gorham, 1995). This is confirmed by the comparison between the information from the questionnaire with the current situation of streets layouts in New-Cairo as one of the most important elements of urban design. The motivating question now, implicitly and often explicitly, is how to design neighbourhoods and the larger community to reduce automobile use. The intent is also to stimulate the interaction of residents by increasing pedestrian traffic and generally improving neighbourhood charm, as well as reducing air pollution and traffic congestion. These goals have given rise to a large but still quite new body of studies on whether and how changes in land use and urban design can change travel behaviour (Crane, 2000).

Not only should urban planning focus on increased population densities; cities should also encourage the development of mixed-use areas. This implies a shift away from strict zoning regulations that have led to a physical separation of activities and functions, and thus an increased need for travel. Instead, cities should be built around the concept of ‘streets’, which can serve as the focus for building liveable communities. Cities should, therefore, encourage mixed land-use, both in terms of functions and in terms of social composition (i.e. with neighbourhoods containing a mixture of different income and social groups) (UN-Habitat,
Different mobility patterns carried out by participants depending on private cars means more of burning fossil fuel, more of air pollution, more traffic congestion, more of economic losses, and above all, more mental and nervous energy wasted during these long journeys which not only affects the productivity of individuals but also affects the quality of urban life in the city in general. The majority of respondents attributed their use to cars for many reasons have been presented previously. But all of these reasons are just side effects of the adoption of the principles strict zoning regulations that have led to a physical separation of activities and functions (see Figure 3, and 7). But by applying the principles of diversity of land use during the process of urban design or urban development ensures access to policies that guarantee more fair distribution of jobs and services at the neighbourhood and city level. On the level of services, almost all the participants rely on the neighbourhood local service area while the majority of them use a private car, a lot of them refer their choices to the difficulty of cutting the distance between their houses and the service area, which is located in the middle of the neighbourhood, while carrying the purchased objects. Hence, this shows the importance of the diversity of land use which will reduce the need for travel within the neighbourhood through the distribution of services horizontally below the residential activity to confirm on the concept of ‘streets’. Participants have indicated this when they asked to describe a street that enhances their sense of safety, by choosing mixed-use street. Walkability and the land-use mixes of neighbourhoods that surround stations are also important to viable public transport services. If people cannot safely and conveniently walk the half-kilometre to or from a station, chances are they will not use public transport (UN-Habitat, 2013). The streets of residential use only are often silent with dim lights, which reduces the sense of safety, especially when walking long distances at night. This discourages the participants who are willing to rely more on the public transportation, this is in addition to the weakness of public transport networks in New Cairo. But That's not the point, the point is to clarify the role and possibilities that can be provided by developing urban forms to support a more sustainable mobility policy in light of the interaction of the participants with the issue raised in the questionnaire for a more sustainable urban development process stems from the needs of the population.

Discussion, and Conclusion

There is a wide variety of urban forms, defined by land use and transportation systems that are not conducive to the provision of ‘efficient’ forms of urban mobility. There can be little doubt that designing neighbourhoods, cities and regions in a way that can reduce private car dependency, promote healthier, more sustainable urban forms and a variety of travel solutions can make the city more accessible to all. Accessibility lies at the core of achieving an urban form that is environmentally sustainable, socially equitable and inclusive. Sustainable mobility is an outcome of how cities and neighbourhoods are designed and take form, but it also shapes the urban form itself. A reinvigorated notion of urban planning, solid institutions and governing structures is therefore required (UN-Habitat, 2013). From documenting, and analysing the data came out from the questionnaire. There is a clear relationship of mutual influence between patterns of urban mobility, transportation means, and urban form characteristics within New-Cairo’s neighbourhoods. The results explained the key role that urban form characteristics play as the main driver to the choices of inhabitants of transportation means and patterns of urban mobility. The results also explained that a lot of inhabitants are willing to reduce the use of the private car and rely more on green sustainable transportation modes but what is preventing them are reasons related to urban form such as
streets layouts. Also the effect of urban form is clear on the level of the “3D’s”: Density, Diversity (of land use), and Design. The density and diversity on the level of services and work opportunities distribution at the scale of neighbourhood and city affect the patterns of mobility on the level of distances and replications of travels. The design also no less important, since its direct impact on mobility patterns and transportation. For example, the majority of the population has agreed that the design of streets in New-Cairo affect their choices of transportation modes also the majority of the population has supported the idea of increasing the number of pedestrian streets. According to the information collected from the field study and analysis of New-Cairo’s neighbourhoods urban form in the light of these information, the paper confirms that urban design, and development can provide an environment that encourages people to adopt a more environmentally friendly lifestyle for less pollution, better health and a more sustainable society. Urban design also plays a key role in providing the appropriate infrastructure to accommodate various means of transport, whether public or green for better accessibility, and connectivity. The conscious urban design has its direct impact on sustainability in order to meet the needs of the present generation without compromising the ability of future generations to meet their own needs.

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IMPACT OF URBAN MORPHOLOGY ON MICROCLIMATE IN HOT DRY ARID CITIES: A STUDY IN CAIRO, EGYPT

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Abstract: Scientists are certain that the global warming is mostly being caused by human activities. Hotter microclimate is known as Urban Heat Island. Urban microclimate is an effective issue on the local and global climates which is influenced by urban morphology. Several literature propose different attempts to improve microclimate that could be achieved through planning a reasonable urban morphology. Unfortunately, modern cities in Egypt does not consider proper urban design principles reaching to hotter Microclimate. Cairo’s urban form features Wide Street, Low rise building, and Low density of buildings; as a result, shaded areas in the streets are scarce. The aim of this research is to confirm the influence of urban morphology on Microclimate. This research investigates the effect of different urban parameters (HEIGHT-WIDTH RATIO, STREET ORIENTATION, BUILDING SPACING, and VEGETATION) on microclimate in the residential area in new Cairo. Numerical simulations, using ENVI-met program, were performed for a hot summer’s day in Cairo for a street canyon. Analysing the effect of modifying the selected urban parameters on Microclimate. Study results indicate that the urban morphology impacts the urban microclimate. The study reveals that street width to building height ratio, vegetation, and orientation have a beneficial impact upon microclimate.

Keywords: Urban Morphology, Microclimate, Arid Climate, ENVI-met

Introduction

The Earth’s Climate is experiencing a gradual increase in the average temperature of the atmosphere and oceans, which is known as the Global Warming (Intergovernmental Panel on Climate Change, IPCC, 2007). The scientific understanding of global warming is increasing. IPCC reported in 2014 that scientists are 95% certain that the global warming is mostly being caused by human activities. Hotter microclimate is known as Urban Heat Island (UHI). United States Environmental Protection Agency approved that the main cause of UHI effect is from the modification of land surfaces. UHI defined by US Environmental Protection Agency is a city or a metropolitan area which is significantly warmer than its surrounding rural area due to human activities.

Literature review showed that planning urban strategies to improve outdoor thermal comfort has many benefits. First of all, it will help in reducing the upward temperature trends due to climate change, which will allow people to move around urban areas. Then, a cooler outside will decrease thermal stress on internal building conditions, which in turn reduce the energy consumption of buildings. And the most important thing is that a well-planned Urban Morphology can significantly reduce UHI effects on local and global climate (Johansson and Emmanuel, 2006; Oke, 2006; Fahmy and Sharples, 2011).

Microclimates are affected by urban morphology. Street Canyon (Height to Width ratio H/W) and Vegetation are the key plan parameters that affect a microclimate (Givoni, 1998; Johansson and Emmanuel, 2006; Oke, 2006). These parameters directly affect the potential of airflow at street level, solar access and therefore urban microclimate (Arnfield and Mills, 1994). Urban built form significantly affect the thermal environment at the micro-scale (Oke, 1981). At the street level, Height to Width ratio (H/W) and Sky View Factor (SVF) alters the
rate of cooling (Oke, 1981). Low SVF can improve the outdoor thermal comfort significantly (Hwang et al., 2011). Varying street geometries in cities significantly influences the outdoor thermal comfort (Johansson and Emmanuel, 2006). Moreover, Arnfield found that the thermal properties of the materials and the canyon geometry promote the rate of cooling (Arnfield and Mills, 1994). Thermal environment of built form is determined by the envelop ratio (Shashua-Bar et al., 2009). Shading effects of trees can significantly reduce Mean Radiation Temperature (MRT) in urban areas (Ali-Toudert and Mayer, 2007). The outdoor thermal comfort can be improved with low SVF (Hwang et al., 2011). Wind speed is the main axis in the relationship between SVF and MRT (Krüger, Minella, 2011). Seasonal shading effects should be thought carefully while making better comfort conditions at street level (Hwang et al., 2011).

Matzarakis and Mayer identified that the thermal stress levels of human depend on shading and clothing (Hwang et al., 2011). Varying street geometry in complex urban environments of Szeged, Hungary shown 15 °c to 20 °c difference, because of, different shading of streets (Myster, 2013). Studies reveal that appropriate urban design and shading by planners and architects can make a significant improvement in outdoor comfort conditions. Appropriate urban design and shading can achieve significant improvement in outdoor climate.

Research Problem

According to United Nation State of the World Population 2007 report (UNFRA, 2007), the majority of the global population are living in urban areas for the first time in history. Since the number of inhabitants in urban areas increases, the physical environment of cities and human activities are expanding and affecting the environmental quality and causing increase in ambient temperatures and pollution.

Since microclimates are being affected by urban morphology, yet urban planning of modern cities in Egypt does not consider vernacular urban design principles reaching to hotter Microclimate (Fahmy and Sharples, 2011). Cairo’s urban form features wide street, short buildings, and detached buildings as a result, shaded areas in the streets are scarce. The outdoor Air temperature increases causing high energy consumption in buildings, and discomfort to pedestrians.

Research scope

This research focuses on the effect of the urban morphology of the Cairene context on the microclimate. The research will focus on the new residential district of Cairo. The study will depend on simulation results.

Research Aim and Objectives

The aim of this research is to understand the influence of urban morphology on microclimate. This research will investigate the microclimatic thermal behavior of street canyon types of urban form in Cairo. The research investigates the effect of manipulating these urban parameters (HEIGHT-WIDTH RATIO, STREET ORIENTATION, BUILDING SPACING, and VEGETATION) on microclimate levels of hot dry arid city.
Methodology

An urban layout in Fifth settlement, New Cairo ((N 30° 7'') (E 31° 23'')) has been used as the Base case shown in Figure 1. Thermal comfort assessment has been done by ENVI-met, It is a three-dimensional microclimate model that can simulate the surface-plant-air interactions within urban environments with a typical resolution of 0.5 to 10 m in space and 10 sec in time. ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. The model includes the simulation of flow around and between buildings and the exchange processes of heat and vapor at the ground surface and at walls. ENVI-met is a Freeware program and is under constant development. Version 4.0 Beta has been used (Bruse, 2008). The main input data used for ENVI-met are based on the weather data file of Cairo airport (No: 623660) on the first of July since this is the hottest day of the year according to Ecotect Analysis 2010 as shown in Table 1. Simulation has been in the period from 11:00 to 22:00. Cassia Leptophylla is a tree used in the models since it is one of the most common trees used in the Egyptian environment. Specifications of the tree are shown in Table 2.

![Figure 1: A satellite photo for typical Urban Morphology in Fifth settlement, New Cairo, Source: Google Earth.](image)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls material</td>
<td>Thickness =0.3</td>
</tr>
<tr>
<td></td>
<td>Albedo=0.3</td>
</tr>
<tr>
<td>Roofs material</td>
<td>Thickness =0.3</td>
</tr>
<tr>
<td></td>
<td>Albedo=0.4</td>
</tr>
<tr>
<td>Start wind speed at 10 m height</td>
<td>2.6 m/s</td>
</tr>
<tr>
<td>Initial temperature of Atmosphere</td>
<td>28.4 °C</td>
</tr>
<tr>
<td>Specific humidity at model top 2500m</td>
<td>8.5 g/kg</td>
</tr>
<tr>
<td>Relative humidity in 2m</td>
<td>35%</td>
</tr>
</tbody>
</table>
Table 2: Cassia Leptophylla specifications (Fahmy et al, 2016).

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Cassia Leptophylla</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliage Shape</td>
<td></td>
</tr>
<tr>
<td>Total Tree Height</td>
<td>12 m</td>
</tr>
<tr>
<td>Maximum LAD Height</td>
<td>8 m</td>
</tr>
<tr>
<td>Foliage Height</td>
<td>9 m</td>
</tr>
<tr>
<td>Measured Albedo</td>
<td>0.085</td>
</tr>
<tr>
<td>LAI (Leaf Area Index) m²/m²</td>
<td>3.18</td>
</tr>
<tr>
<td>LAD (Leaf Area Density)</td>
<td></td>
</tr>
<tr>
<td>1m</td>
<td>0.0</td>
</tr>
<tr>
<td>2m</td>
<td>0.12</td>
</tr>
<tr>
<td>3m</td>
<td>0.17</td>
</tr>
<tr>
<td>4m</td>
<td>0.25</td>
</tr>
<tr>
<td>5m</td>
<td>0.36</td>
</tr>
<tr>
<td>6m</td>
<td>0.48</td>
</tr>
<tr>
<td>7m</td>
<td>0.56</td>
</tr>
<tr>
<td>8m</td>
<td>0.54</td>
</tr>
<tr>
<td>9m</td>
<td>0.48</td>
</tr>
<tr>
<td>10m</td>
<td>0.25</td>
</tr>
</tbody>
</table>

The thermal comfort assessment will be presented by the modified predicted mean vote (PMV) at 1.2m, at 11:00, 16:00 and 22:00. PMV predicts the average thermal response (on a scale ranging from 'very hot' to 'very cold', from -1 to +1 represent the comfort zone) of a group of people exposed to a set of environmental conditions such as air temperature, humidity and wind speed. Thermal comfort assessment has been made eight times, changing only one different parameter each time as shown in Table 3. In case 1, the building Height is 8m, street width is 20m accordingly the height width ratio is 0.4, the street is oriented to North-South without trees, and the buildings are detached with spacing 6m as shown in Figure 2. In case 2, only the street width was modified to be 8m, accordingly the H:W ratio is 1 as shown in Figure 3. In case 3, the street orientation was modified to be East-West oriented as shown Figure 4. In case 4, the building Height is 8m, street width is 8m accordingly the height width ratio is 1, the street is oriented to North-South without trees, and the buildings are Attached as shown in Figure 5. In case 5, only the building height was modified to be 20m, accordingly the H:W ratio is 2.25 as shown in Figure 6. In case 6, the same parameters used in case 5 but urban trees were added to the model as shown in Figure 7. In case 7, the same parameters used in case 1 but urban trees were added to the model as shown in Figure 8. In case 8, the same parameters used in case 4 but urban trees were added to the model as shown in Figure 9.
Table 3. The 8 simulated cases using ENVI-met with the list of their tested parameters.

<table>
<thead>
<tr>
<th>Cases</th>
<th>H/W Ratio</th>
<th>Street Orientation</th>
<th>Trees</th>
<th>Building Spacing</th>
<th>PMV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.4</td>
<td>1</td>
<td>2.25</td>
<td>N-S</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Base Case</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Same as Case 1 Except H:W Ratio PMV of Case 2 better than Case 1</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Same as Case 2 Except Orientation PMV of Case 2 better than Case 3</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Same as Case 2 Except building Spacing PMV of Case 4 better than Case 2</td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Same as Case 4 except H:W Ratio PMV of Case 5 better than Case 4</td>
</tr>
<tr>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Same as Case 5 except Trees PMV of Case 6 better than Case 5</td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Same as Case 1 except Trees PMV of Case 7 better than Case 1</td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Same as Case 4 except Trees PMV of Case 8 better than Case 4</td>
</tr>
</tbody>
</table>

Figure 2: Case 1  
Figure 3: Case 2  
Figure 4: Case 3  
Figure 5: Case 4
Results analysis

The results of the experiment stated in the methodology had been as follow: In case 1, the average PMV was 6.0, 6.5 and 3.2 at 11:00, 16:00 and 22:00 respectively as shown in Figure 10, 11 and 12. In case 2, the average PMV was 5.5 and 6.5 except for the east pedestrian walk, the PMV was 4.5 and 5.5 at 11:00 and 16:00 respectively, and the average PMV was 1.5 at 22:00 as shown in Figure 13, 14 and 15. In case 3, the average PMV was 6.0, 6.5 and 1.5 at 11:00, 16:00 and 22:00 respectively as shown in Figure 16, 17 and 18. In case 4, the average PMV was 5.5 except for the east pedestrian walk the PMV was 5.0 at 11:00 as shown in Figure 19. The average PMV was 6.5 except for the west pedestrian walk, the PMV was 5.5 at 16:00 as shown in Figure 20. And the average PMV was 1.5 at 22:00 as shown in Figure 21. In case 5, the average PMV was 3 except for the east pedestrian walk, the PMV was 2 at 11:00, showing a remarkable change as shown in Figure 22, and the average PMV was 2.5 and 0.0 at 16:00 and 22:00 respectively as shown in Figures 23 and 24. In case 6 at 11:00, the average PMV was 3 except for the east pedestrian walk the PMV was 2, and the west pedestrian walk PMV was 2.5 shown an improvement due to urban planting as shown in Figure 25. The average PMV was 2.5 and 0.0 at 16:00 and 22:00 respectively as shown in Figures 26 and 27. In case 7, the average PMV was 6 except spaces under trees, the PMV was 5.0 at 11:00 as shown in Figure 28. And the average PMV was 6.5 except spaces under trees, the PMV was 5.5 at 11:00 as shown in Figures 29 and 30. In case 8, the average PMV was 4.0 except for the east pedestrian walk, the PMV was 2.0 at 11:00 as shown in Figure 31. And the average PMV was 2.5 and 0.0 at 16:00 and 22:00 respectively as shown in Figures 32 and 33.

Obviously, results had shown that Urban Morphology (HEIGHT-WIDTH ratio, STREET ORIENTATION, BUILDING SPACING, VEGETATION) affects the Microclimate. First of all, comparing between cases 1 and 2, and cases 3 and 4 had shown that, HEIGHT-WIDTH ratio (H:W) had a clear impact on PMV as shown in Figures 10 to 15 and 16 to 21. Then, comparing between cases 2 and 3 had shown that, STREET ORIENTATION affected PMV significantly as shown in Figures 13 to 18. Moreover, comparing between cases 2 and 4 shown that, BUILDING SPACING (Attached-Detached) manipulated PMV as shown in Figures 13 to 15 and Figures 19 to 21. Last but not least, comparing cases 1 and 7, 5 and 6, and 4 and 8 had shown that, VEGETATION (Urban Trees) impacted PMV as shown in Figures 10 to 12, 28 to 30, 19 to 27 and 31 to 33.
Figure 10: Outdoor PMV mapping for case 1, 11:00
Figure 11: Outdoor PMV mapping for case 1, 16:00
Figure 12: Outdoor PMV mapping for case 1, 22:00

Figure 13: Outdoor PMV mapping for case 2, 11:00
Figure 14: Outdoor PMV mapping for case 2, 16:00
Figure 15: Outdoor PMV mapping for case 2, 22:00

Figure 16: Outdoor PMV mapping for case 3, 11:00
Figure 17: Outdoor PMV mapping for case 3, 16:00
Figure 18: Outdoor PMV mapping for case 3, 22:00

Figure 19: Outdoor PMV mapping for case 4, 11:00
Figure 20: Outdoor PMV mapping for case 4, 16:00
Figure 21: Outdoor PMV mapping for case 4, 22:00
Conclusion

During daytime, all the streets were uncomfortably hot with the PMV values well above the comfort zone. Changing the H:W Ratio had a noteworthy effect on thermal sensation. Also, the vegetation enhanced thermal sensation. Attached buildings made better shading for the streets affecting thermal comfort positively but if the streets are oriented other than north south, the prevailed wind won’t be at its best case. At night, Case 1 recorded a high PMV causing an Urban Heat Island. The significance of improving the daytime comfort in the neighbourhoods, by stipulating appropriate built geometry and orientation in the new neighbourhoods. Also if the concept of shading by trees in the wider streets can be adopted in urban morphology, it can improve the comfort conditions to a significant level.

References


Ward-wise Planning and Distribution of Parks and Gardens Using Network and Spatial Analysis, Case Study of City of Indore

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Abstract: The high rate of urbanisation in the developing countries has led to a rapid increase in the percentage of urban population making it difficult for cities to accommodate more inhabitants. In order to sustain this large and increasing urban population, infrastructural provisions in the growing urban centres becomes exorbitantly important.

Parks and Gardens (Public open spaces) can be seen as a crucial element of the urban infrastructure that have an immediate effect on the quality of life of the people. This significance of public open spaces needs to be understood by cities of developing countries to make the cities more liveable. This thesis deals with forming a distribution network of parks and gardens using ArcGIS so as to make the cities more liveable, environmentally sustainable and also reduce urban heat. The aim of the study is to use network analysis and spatial analysis to work out the distribution of parks and gardens around the city to improve accessibility.

The research methodology includes classification of parks and gardens into hierarchy based on area as per URDPFI guidelines in India, Selection of ward for study, network analysis (on ArcGIS) for analysing accessibility of parks, Spatial analysis (on ArcGIS) to identify potential areas for location of new parks. The final result of the study includes provision of distributed and accessible network of parks across the city, identification of deficit areas in terms of availability and quality of parks and provision of new parks where required.

Keywords: Open spaces, Parks, Gardens, Network Analysis, Spatial analysis, Ward/Administrative divisions

Introduction

Over the years, the world population is on a steep increase. In the mid-2017, the total population was calculated to be around 7.6 billion, i.e., the population has increased by one billion approximately over the last twelve years. (United Nations, Department of Economic and Social Affairs, Population Division, 2017).

This population is estimated to rise in the forthcoming years. Along with this rise in population, the cities around the globe are also facing rise in their respective population.

Open spaces can be seen as a crucial element of the urban infrastructure that has an immediate effect on the quality of life of the people. This significance of open spaces or urban open spaces needs to be understood by cities of developing countries to make the cities more liveable.

The cities face various challenges in terms of open space planning. Most Indian cities face lack of parks as compared to standards given by various guidelines. Also, in cities where there is proper availability of parks and gardens, their quality and maintenance may become a concern. The poor maintenance of parks and gardens also becomes an issue for open space planning in a city.
Another major problem is the low level of pedestrian access to the parks and as such, no networking to connect various open spaces of cultural and recreational importance. This study focusses on this crucial element and its significance in urban infrastructure.

Objectives

The objectives of the study are as mentioned below:

- Study the distribution of existing parks and gardens in the area, classify the parks based on hierarchy
- Analyse accessibility of existing parks (pedestrian access, public transport)
- Identification of deficit areas
- Proposals and recommendations for improving accessibility and networking of parks

Data and Research Methodology

The detailed research methodology for the study is as follows:

**OBJECTIVES**

<table>
<thead>
<tr>
<th>OBJECTIVE 1: Study the distribution of existing parks and gardens in the area, classify the parks based on hierarchy</th>
<th>DATA REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Data: Marking the location of parks in the ward</td>
<td>Secondary data: Aerial images, data from government authorities and documents, URDPFI Guidelines</td>
</tr>
<tr>
<td>Primary data: Field survey to mark the entry points of parks in the ward, Existing uses and characteristics of parks</td>
<td>Secondary data: Literature: Methods of assessing accessibility, network analysis, toolkits, guidelines, Existing Road network, Hierarchy of parks as mentioned above, Operational Public Transport Routes</td>
</tr>
<tr>
<td>Results from analysis</td>
<td>Geographical Features of the site Land Use (Primary Survey) and other details like built-up area, connectivity of the ward etc., results from analysis</td>
</tr>
</tbody>
</table>

Figure 1. Data Requirement and Research Methodology
Figure 1 presents the detailed data requirements to fulfil each objective of the study. It also elaborates on the research methodology that has been followed.

Study Area Profile

This paper deals with Indore, which is a city located in the state of Madhya Pradesh in India. Indore has transformed from a traditional commercial urban centre into a modern dynamic commercial capital of the state. Indore, the most prominent city of Madhya Pradesh and the district headquarter of the district with the same name is situated on the western part of the Malwa (historically known as Deccan plateau) on the banks of two small rivers, the Khan and the Saraswati. The city is currently the most populated city of Madhya Pradesh. Indore has been a centre of affluence due to flourishing trade and commerce right from the beginning. It is the biggest commercial centre and is termed as the business capital of Madhya Pradesh.

Open spaces in the Indian scenario

The discussion of what may be defined as an open space is open-ended. Over the years, many notable authors and researchers have come up with their idea of an open space. “An area, forming an integral part of the plot, left open to the sky.” (Nation Building Codes, 2008).

Due to rapid urbanisation, the built form is ever increasing in the Indian cities resulting in lack of open spaces throughout the cities. This needs to be looked into in order to maintain the ecological balance as well as ensure a sustainable and resilient urban area. It is crucial to any human settlement to ensure the balance between the built and the natural environment.

Hierarchy of Open spaces

The hierarchy of urban open spaces according to Urban and Rural Development Plan Formulation and Implementation (URDPFI) guidelines is given in Figure 3. The URDPFI guidelines defines the various categories of open spaces in the Indian context. It also mentions the minimum area and population requirements for the respective categories of open spaces.
Data Collection and Analysis

The presence of open spaces in the city act as the lungs of the city. Due to rapid urbanisation, the built form is ever increasing in the cities resulting in lack of open spaces throughout the cities. Presence of open spaces or rather properly planned open spaces can help reduce the pressure of environmental degradation to a large extent. These open spaces include playgrounds, parks, forest areas, ecological areas, water bodies, etc.

Assessment of Parks and Gardens at city level

In Indore, these spaces are lacking and also, the existing spaces are poorly maintained. The city has experienced high rates of population growth but the there is no proportionate growth in the green spaces. The existing green spaces have proved to be unsuccessful for catering to the large population of the city.

The classification of parks and gardens is done based on the hierarchy mentioned in URDPFI Guidelines that are followed in India. An area based classification based on the same guidelines is shown in the subsequent figure.
The total area under Indore Municipal Boundary is 110 sq km, out of which the area covered under parks and gardens is 9.68 sq km, i.e., 8.9% of the total area. According to standards, this should be around 18-20% according to Indian standards.

**Accessibility analysis at city level**

At the city level, accessibility through public transport is given importance. This is because the parks that lie higher in the hierarchy such as district parks, city level parks, basically, parks that are open to all the residents of the city and people coming from outside in case of fairs, etc cannot only be seen as being accessible by pedestrian movement. That is why it becomes important to make these parks accessible through public transport as well. Operational bus routes are considered for this analysis and parks with higher area (<5000) have been marked as facilities. The results of the analysis are shown in the subsequent maps,
**Detailed analysis of selected ward – Ward 54**

This section of the report focuses on detailed characteristics of the selected ward, ward 54 of Indore Municipal area. Indore Ward No 54, with population of about 30,213 is Indore city's the 25th most populous ward, located in Indore sub district of Indore district in the state Madhya Pradesh in India.

![Map showing existing scenario of ward 54](image)

**Existing Scenario of Parks and Gardens**

The total area of Ward 54 is 1180814 sq m and the total area covered by parks and open spaces is 305957 sq m which accounts for 25.9% of the total area of the ward.

There are in total, 11 parks in the area. For the purpose of analysis, these parks have been classified based on area (hierarchy as given in URDPFI Guidelines), the existing condition and use of the parks is also studies. The following map shows the location and names of the parks.
Table 1. Existing parks in ward 54

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>NAME OF THE PARK</th>
<th>AREA OF THE PARK (in sqm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lal Bagh Park</td>
<td>17,600</td>
</tr>
<tr>
<td>2</td>
<td>Nidhi Vihar Colony Garden</td>
<td>2,223</td>
</tr>
<tr>
<td>3</td>
<td>Nidhi Vihar Colony Garden</td>
<td>2,399</td>
</tr>
<tr>
<td>4</td>
<td>Sachchidanand Colony Park</td>
<td>1,566</td>
</tr>
<tr>
<td>5</td>
<td>Sachchidanand Colony Park</td>
<td>3,467</td>
</tr>
<tr>
<td>6</td>
<td>Madhuban Colony Park</td>
<td>2,600</td>
</tr>
<tr>
<td>7</td>
<td>Indira Gandhi Nagar Park</td>
<td>20,000</td>
</tr>
<tr>
<td>8</td>
<td>Dusshera Maidan</td>
<td>8,000</td>
</tr>
<tr>
<td>9</td>
<td>Aakarsh Udyan</td>
<td>4,300</td>
</tr>
<tr>
<td>10</td>
<td>Aakarsh Udyan</td>
<td>4,300</td>
</tr>
<tr>
<td>11</td>
<td>Lokmanya Nagar Park</td>
<td>1,500</td>
</tr>
</tbody>
</table>

Network Analysis for Ward 54

This section explains a major part of analysis done using network analyst tool in ArcGIS. The aim of this analysis is to analyse the park accessibility. Accessibility is considered as a possibility to access, openness, or closeness of the locality, access to various age and social groups, or, in the narrower perspective, as a time or spatial distance (Hudecek, 2011).

The accessibility calculations were performed in the software as walking time along the streets. The accessibility target points—the entrances to the individual parks—were localized using GPS coordinates. The resulting accessibility zones around the parks then logically overlap. Accessibility of the parks needed to be calculated using the hierarchy of parks. The time-based accessibility of the parks was entered into the analysis in the following manner:
Neighbourhood Park: 500 m walking distance, 5-10 min walking time
Lal Bagh Palace Garden: 15 min travel time by public transport

The first step is to work out the hierarchy of the existing parks and gardens. The next step is to identify the entry points of each of the parks, which were marked at the site and were then localised on the software. These become the facilities in the network analysis. The entry points have been marked in the subsequent maps. This step is followed by feeding in the constraints in order to solve the network analysis. They are entered in terms of comfortable walking distance from the facilities. The result of the network analysis is shown in the subsequent maps.

Figure 9. Network Analysis – Ward 54

Figure 10. Map showing Deficit areas
Out of a total of 6140 households in the ward, 719 are not catered by the existing parks and gardens and fall under the deficit area.

Proposals and Recommendations

The proposals and recommendation area based on:
  - Results obtained from primary survey (to know the needs of the residents)
  - Results obtained from analysis of primary and secondary data (Network analysis to find out the deficit area)

The proposals and recommendation given in the chapter can be broadly classified under following heads:
  - To improve quality of parks and gardens
  - To improve accessibility of parks and gardens within the ward
  - To make sub city park, district park accessible through public transport

City Level Proposal

Proposal 1: To make sub-city park, district park accessible through public transport

At the city level, it becomes important to make sub city level and district level parks accessible by public transport. For this, the network analysis considering the operational bus routed in the city has already been carried out and the results are elaborated in the previous sections of the report. The network analysis results in deficit areas that are shown in the map below.

Ward Level Proposal

The proposals in this section are specific proposals for the selected ward, i.e., Ward 54.. However, this can be seen as a sample area and such proposals can be made for all the other wards based on the results of network analysis for that particular ward. This ward can be seen as a sample ward.

Proposal 2: Proposal to improve accessibility of parks and gardens in ward 54
According to the network analysis done for ward 54, the households that have access to parks within 5 and 10 min walking distance have been identified. This gives the deficit areas. Out of 6140 households in the ward, 719 households are do not have access to parks within walking distance. This amounts to 12% of the total households. A green network with the existing road network can be proposed linking all the parks and gardens.

For deficit areas, since it becomes difficult to acquire land for proposing new parks, buffer zones along the streets joining the nearest parks together can be created. Heavy plantations can be done in this buffer based on the species available and which provide the maximum shade.
Proposal 3: To improve the quality of existing parks and gardens

Some of the existing parks and gardens are maintained by Indore Municipal Corporation, while other housing area parks are maintained by the residents using the park.

In Indore, in area where parks are present their usability is compromised due to poor quality and maintenance of the parks and gardens. One such example is the Lal Bagh palace Garden, Lokmanya Nagar Garden, Nidhi Vihar Colony Park, Dusshera Maidan etc. In such a case, even if the park is present, it does not hold any value.

Recommendations for improving quality of existing parks:

- Local authorities, namely, IMC and IDA to work in collaboration and ensure the maintenance of not only city level and strict level parks, but also housing area and neighbourhood parks.
- For parks in a private housing society, guidelines are already there. Strict laws can be made to ensure that these are well maintained and well connected to the green network proposed. Fines can be put in place by local authorities.
- Proper street lighting
- Measures to improve safety and security so as to make it accessible to all sections of the society.
- Improve the parks in terms of adding aesthetic and functional elements
- Provide recreational facilities in the parks such as walkways, benches
- Provide guidelines for introducing productive activities in the parks such as appropriate plantations, nurseries, etc.

Conclusion

With the help of detailed data analysis, aerial photos, and cross county exploration, unused and deprived areas with some potential for the construction of new parks have been identified. Parks and Gardens (Public open spaces) can be seen as a crucial element of the urban infrastructure that have an immediate effect on the quality of life of the people.

The first objective is to study the distribution of existing parks and gardens in the area and classify the parks based on hierarchy. To analyse the accessibility of individual parks, it was first necessary to classify them according to their importance. The hierarchy of public open spaces in general is of key importance for an understanding of the overall composition of the city. For this purpose, Hierarchy of parks as given in URDPFI guidelines is considered.

The second objective is to analyse the accessibility of existing parks. This includes pedestrian access as well as access through public transport. Also, accessibility in terms of providing access to all age groups, disabled people as well women is considered. The accessibility calculations were performed in the software as walking time along a pavement. The accessibility target points—the entrances to the individual parks— were localized using GPS coordinates. The resulting accessibility zones around the parks then logically overlap. For calculating the accessibility through public transport, pedshed analysis from the existing bus stops is conducted to find out the deficit areas.

The third objective is to identify the deficit areas in term of accessibility to existing parks and gardens. The deficit area are found by the result of network and pedshed analysis and overlapping the results with population density.

The last objective is to give proposals and recommendations for improving accessibility of parks. In order to fulfil this objective, the results from analysis are considered and various solutions to fit the existing situation are proposed.
The final result of the study includes provision of distributed and accessible network of parks across the city, identification of deficit areas in terms of availability and quality of parks and provision of new parks where required.

Simple proposals such as introducing new bus stops in deficit areas, creation of green networks throughout the city, improved road sections, ramps etc, can go a long way in enhancing park accessibility.

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Simulation Study on the Environmental Sustainability of Traditional Blocks in Xi’an City

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Abstract: Urban climate change and its impacts on living environment have become an important issue with the high-speed and large-scale urban development in most Chinese cities. The urban micro-climate affects the citizens’ living comfort and safety, which is strongly related to urban typology. Meanwhile, the traditional old blocks are the valuable historical urban components in Xi’an, a historical Chinese city. The balance between renewal and environmental improvement of old urban blocks have attracted significant attention in urban renovation, thereby indicating the need to study and improve the thermal environment in such urban areas. This study aims to reveal the relationship between the old urban block planning and current environmental conditions in Xi’an to develop a guideline for urban renovation in historical districts. Shuyuanmen District in Xi’an with a 300-year history is selected in this study. Urban environmental simulation program ENVI-met is used for simulation and evaluation. Solutions, such as the adjustment of building facade and open space planning and the addition of urban vegetation, for promoting urban thermal environment and urban convenience are simulated and evaluated. Moreover, a development method for the guideline to balance the living convenience and thermal environment in old urban blocks is proposed. The urban environmental simulation helped to indicate the specific locations need to be promoted, helped to revise the proposed solutions in the design step. This study contributes to sustainable urban planning in historical districts and provides recommendations for related policy development.

Keywords: environmental sustainability, traditional block, urban renovation, thermal environment.

Introduction

In the process of urban planning and urban development, climate issues have constantly been in a secondary position under the important and dominant influencing factors, such as politics, economy, society, transportation, and landscape. After the industrial revolution, few attention have been focused on climate elements in urban planning and urban design with the development of technology and the improvement of humans’ ability to transform the environment [Baofeng et al., 2008]. Urban design based on climatic conditions is conducive to create a comfortable and pleasant urban environment and reduces many problems caused by the urban heat island phenomenon. Urban design provides practical significance for energy conservation in cities and buildings [Zhixi, 1992].

By contrast, the current trend of human life has gradually pursued the quality of life. Therefore, the shape of neighborhood in a city is no longer a solution to the basic needs of life and cannot meet the standard of human comfort [Xiujuan and Haicun, 2009]. A high building density is the major form in a city, and the traditional block is a typical example.
Currently, the transformation of old blocks has become an unavoidable problem in urban development [Chong and Ang, 2013]. Therefore, the use of climate factors in planning and reconstruction of old urban blocks to determine the reconstruction plan provides theoretical and practical significance.

**Urban transformation**

A traditional area in a city is mixed with residential and commercial areas, which is usually located in the middle circle of the urban area and is the product of early planning short-sightedness. A mixed residential area has various concentrated types of spaces, such as residential, commercial, industrial, and municipal facilities, due to historical reasons. The roads are narrow and buildings are dense. The level of population purchase is low and is unable to bear the cost of improving home ownership. In the mixed area, industries are dominated by small enterprises, which makes it difficult to redevelop. According to the state’s principle of reforming old areas, developers must expand or renovate roads and add public supporting facilities. Thus, the cost of reforms remarkably increases [WISENOVA, 2017].

Real estate development companies frequently avoid the sites with high living density, poor location conditions, because it’s difficult to balance the funds. Therefore, the government usually combines and distributes lands with good locations and divides these into pieces to achieve unified planning. Therefore, a company that aims to participate in the transformation of a large area of old cities inevitably encounters a mixed-area reconstruction. A real estate development company must also consider the influence of mixed-area on its single-item projects due to the upgrade of grades and development levels of remodeled areas [WISENOVA, 2017].

**Urban vegetation**

High building density in traditional blocks leads to the deterioration of thermal environment and increases the regional heat island effect [Rosenfeld, et al., 1995]. Weiwu used remote sensing images and Landsat TM data to analyze 52 residential areas in Hangzhou. The influence of building density on surface temperature is 22.8 % [Weiwu and Yongyong, 2010]. Chen conducted a comparative analysis on the spatial pattern of the heat island effect in Dongguan from 1990 to 2005 and concluded that the high building density and the intensity of heat islands in a traditional block exhibit a linear relationship with a value of 0.89 [Minghu et al., 2011]. By contrast, several scholars have believed that an appropriate increase in building density aids in improving the thermal environment. Ewing assumed that high building density indicates that each household has small areas and external walls, and high energy storage leads to less energy and carbon emissions. These conditions improve the thermal environment. Ewing and Rong also believed that the heat island effect reduces winter heating energy consumption in the United States [Ewing and Rong, 2008]. On the basis of the abovementioned studies, building density is a main factor that affects the regional thermal environment in traditional urban areas. However, the results are different for different research areas.

In this study, a micro-scaled traditional district in Xi’an was selected, and the numerical simulation ENVI-met was used to evaluate the impact of urban typology change on urban climate change. The effects of building density, building styles, and vegetation system design in the districts were indicated to demonstrate the mechanism of urban climate change in Xi’an. These technical analyses contribute to environmental policy development for urban climate
change mitigation.

**Methodology**

*ENVI-met simulation*

In this study, ENVI-met was used to stimulate different improvement effects in the study area and the environmental conditions for the selected traditional district in Xi’an. ENVI-met is designed to stimulate the surface-plant-air interaction in an urban environment with a typical resolution of 0.5 m to 10 m in space and 10 s in time. The input model was stimulated for 30 hours and is accurate and stable. The following defined factors of the area model were inputted: buildings, vegetation, soils, and receptors.

In this study, the area from satellite images from the BaiDu Map (satellite image in Table 1) was selected, and the study area image was investigated. Then, a computer-aided design (CAD) model was constructed based on the image. The CAD image of the study area (CAD map in Table 1) was imported to ENVI-met, and the file was edited (ENVI-met input data in Table 1) in cubic grids of 125 m³ (5 m×5 m) to simulate the related parameters of thermal environment. For the simulation, the initial parameters of the ground material inputted in the software are shown in Table 3, and a distance of buffer area is set to reduce the inference from surrounding buildings outside of the selected area.

<table>
<thead>
<tr>
<th>Table 1. Satellite Image of Shuyuanmen District and simulation domain data.</th>
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</thead>
<tbody>
<tr>
<td><strong>Satellite image</strong></td>
</tr>
<tr>
<td><img src="image1.png" alt="Satellite Image" /></td>
</tr>
</tbody>
</table>

**Study area**

Xi’an is an ancient capital city in ancient times and is located in a cold region in China. A typical traditional block called Shu Yuanmen district in Xi’an was selected for this study. Shu Yuanmen district is located inside of the first ring road of Xi’an, which is in the east side of the south gate of the old wall, and is the carrier of urban history and culture. Shu Yuanmen district was initially developed since the Ming dynasty (1368-1644) and became to be an antique commercial street with architectural styles during Ming and Qing (1636-1912) dynasties. Shu Yuanmen district reflects the historical development and cultural inheritance of the city.

![Shu Yuanmen district photos](image4.png)
Simultaneously, this historical district is also a residential area, and its physical space is effected by the residents’ activities. The old city has gradually declined and historic districts have become the main settlement for low-income citizens with the urbanization of Xi’an. Expanded constructions are illegally added to the historic district, and the original fragile green space system is destroyed due to population expansion. In this area, building density is relatively high, and building height is low, with only two to three floors. Meanwhile, several old residential one-story houses in the area are protected as historical sites. Shu Yuanmen district is a traditional historical area with residential and commercial functions (Figure 1).

**Urban reform in traditional community**

In this study, two methods were proposed to improve the thermal environment of this district. Several existing idle lands and removable old residential buildings were organized in the region through field investigation (Figure 2 and Figure 3). Then, these elements were transformed to improve the thermal environment in the district.

![Figure 2. Shu Yuanmen district’s regional function status map.](image)

![Figure 3. Street view of open spaces in Shu Yuanmen district (photo A, B, C refer to the “A, B, C” points that indicated in figure 2).](image)
Vegetation

Vegetation areas are added in open spaces, as shown in Figure 2. Large amounts of heat and carbon dioxide are absorbed from the surrounding environment, and water is released in the atmosphere in a gaseous form through transpiration and photosynthesis of vegetation, which remove heat and reduce air temperature. In the new simulated model, these areas are transformed into residential green areas in Shuyuanmen blocks.

During the field research, we determined several public spaces that can be remodeled, which are located on two sides of the main road in Shuyuanmen District. These spaces were covered by vegetation in the new model.

Vegetation and Building

After the addition of green plants, the building forms in several parts of Shu Yuanmen district are considered and transformed. On the basis of existing studies, enhanced ventilation can effectively improve the regional thermal environment. Steemers.K selected six different layouts of building combinations to simulate the wind speed of regional environment and determined that the ventilation rate in the street space is the highest and the ventilation rate of building space combined with the courtyard is the lowest when the building is parallel to the wind direction [Ratti et al., 2003].

On the basis of these studies, two residential areas (every area is 50 m*50m) are transformed to obtain a wide space for ventilation and heat dissipation. The two areas are located at the edge of the residential area and are near to secondary urban roads. This condition is because several historically protected areas exist in Shu Yuanmen district and heights near the old buildings are limited. In addition, narrow roads are not conducive to the passage of cars in Shu Yuanmen district. The two residential areas, which have close proximity to secondary urban roads, can facilitate the establishment of parking lots in the reconstruction area. Next, old low-rise buildings that are not suitable for living are demolished in the two selected areas. Then, new apartment-style buildings are constructed for residents, and parking lots and greening are established at the same time.

The demolished construction area (3150 m²) in the original model was verified to determine the size of an apartment. The per capita living area is 30 m² in Xi'an and roughly 105 households should be placed in new apartments based on “Xi'an City Building Demolition Management Regulations” [Xi'an Municipal Government, 2014]. A living space with 9 m² was added to each household (total residential area of 4095 m²) based on “Xi'an City Building Demolition Management Regulations.” We planned two 18-storey apartment buildings with parking plots and plants in the two open spaces for further discussion.

<table>
<thead>
<tr>
<th>Table 2. Modification plans for Shu Yuanmen district</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation</td>
</tr>
</tbody>
</table>

![Vegetation](image1.png) ![Vegetation and building](image2.png)
Table 3. Details of the input parameter initialization for the simulation.

<table>
<thead>
<tr>
<th>Category</th>
<th>22nd July, 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time</td>
<td>22:00</td>
</tr>
<tr>
<td>Duration</td>
<td>30 h</td>
</tr>
<tr>
<td>Wind speed</td>
<td>1.5 m/s</td>
</tr>
<tr>
<td>Wind direction</td>
<td>South west</td>
</tr>
<tr>
<td>Specific humidity in 2500 m</td>
<td>7 g/kg</td>
</tr>
<tr>
<td>Relative humidity in 2 m</td>
<td>68%</td>
</tr>
<tr>
<td>Building interior temperature</td>
<td>26.97 °C</td>
</tr>
</tbody>
</table>

**Environmental evaluation**

After the simulation, we extracted the relevant parameter images and box plots at 2 pm and analyzed the average data of the entire day.

**Vegetation**

During the field research, the original model was changed and simulated to obtain new results. Figure 4 shows that low wind speed area is larger than the status quo after increasing the green space of Shu Yuanmen district, which is located in the green area. This phenomenon is clearly shown in Figure 4, which contains the average value throughout the day. After increasing the green open space, the average value of wind speed slightly changed, which decreased to 0.09 m/s.

As shown in Figure 5, the more public green areas are, the larger the area of low-temperature areas will be. However, this condition is not obvious based on the average temperature curve of the day. Therefore, we focus on the results in 2 pm for data comparison. The highest value slightly decreases, the lowest value remarkably increases, and the average value decreases by 0.82 °C. Although increasing the number of trees can decrease the temperature, the reduction in wind speed also hinders cooling. As shown in Figure 6, mean radiation temperature is relatively low in the green area as a whole. Simultaneously, most of the spaces surrounding the greening have low radiation temperature. This condition shows that the increase of greening can create many low radiation temperature areas to provide comfort to people. More covers result in lower sky view factor. This condition is clearly shown in Figure 7.

**Vegetation and Building**

After increasing the amount of vegetation, the model was modified and evaluated by simulation. As shown in Figure 4, the low wind speed areas had an obvious increase, especially in area lower than 0.6 m/s. This phenomenon is presented in Figure 9, which shows the average wind speed value. One reason for this condition is the increase of greening and high buildings can obstruct the wind.

For air temperature, the areas with temperature from 29 °C to 30 °C remarkably increased after improvement. This condition is because the newly-built area focused on residential functions in an apartment building to allow many public green spaces to decrease the surrounding air temperature. As shown in Figure 6, low radiation temperature area is increased. The radiation temperature of the green coverage area is reduced, and the high-
value area over 65.50 °C disappears. Figure 7 shows that the sky view factor decreases in size with increasing building height and greenery.

**Discussions**

In this study, the transformation by the addition of vegetation and building renovation was compared and evaluated. The evaluation results were summarized after the environmental simulation and analysis on simulation outcomes.

Status quo  Vegetation  Vegetation and buildings
Figure 4. Wind speed distribution in the middle of a summer day (22 July 2016) at 1.5 m height.

Status quo  Vegetation  Vegetation and buildings
Figure 5. Air temperature distribution in the middle of a summer day (22nd July, 2016) at 1.5 m height.

Status quo  Vegetation  Vegetation and buildings
Figure 6. Mean radiant temperature in the middle of a summer day (22 July 2016) at 1.5 m height.
Firstly, the increase in the amount of plants decreases the air temperature. The increase in vegetation could promote the regional microclimate. Plants improve microclimate by blocking the solar radiation and regulating the temperature. The dense canopy can block the sun's radiation, and part of the sunlight can be absorbed and reflected by trees and other plants. Thus, the sunlight that penetrates through the leaf gap in the ground is remarkably reduced. The temperature of solar radiation in green areas is reduced by approximately 14%
compared with non-green areas, which reduces the degree of heat and severe solarization. However, the increased green area in the simulation has a small effect on the overall temperature of the large area because the open spaces for adding vegetation are limited compared with the entire district. Therefore, the thermal environmental improvement of greening locations and scales will be verified in future studies by selecting different scale regions.

Second, the relevant parameters of the thermal environment changed during building renovation. In the current transformation of the old city, the architect mainly used building transformation to update the old urban space. However, the improvement of thermal environment was not considered. In this research, we modified several residential buildings and conducted simulation verification. As shown in the temperature and radiation temperature graphs, a certain improvement in the thermal environment was observed after the buildings were changed. In the future study, we will determine the building height, building density, and location of reconstructed buildings suitable for the traditional block in the city, the relationship between these factors, and the improvement of the thermal environment.

**Conclusion**

In this study, the relationship between the renewal mode of traditional districts and their thermal environment are analyzed based on the improvement of thermal environment in traditional old districts of the city. Greening the traditional districts that with high building density and low-rise buildings, such like Shu Yuanmen district, can promote the local thermal environment. Because the environmental impact for promoting the thermal environment by adding vegetation in old districts is limited, several old residential buildings are demolished, and the new centralized residential buildings are proposed, in order to induce wind flow from outside of the district and reduce the air temperature in summer. The renovation proposal in this study is demonstrated to improve the residents’ thermal comfort and enlarge the public space for greening and parking. This condition provides many possibilities to improve the thermal environment of traditional districts. However, in the process of urban redevelopment, it is still necessary to consider the limitations of the building height in the district and the traffic demand of the new-build residential buildings in the converted area. The updating and renovating methods for traditional districts in the city and the evaluation system of thermal environment comfort should be clarified in future studies. Meanwhile, the effectiveness of thermal environment improvement from the existing updated traditional neighborhoods should be verified. The effective traditional street renovation model for urban environmental improvement contributes to the redevelopment of the historical city.

**Acknowledgements**

This research is supported by the Young Scientists Fund of the National Natural Science Foundation of China (Grant No. 51608439).

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Comprehensive Evaluation of Spatial Texture in Historic District: The Case of Sanxue Street Historic District

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Abstract: The protection and planning of historic districts is an important topic in urban development in recent years. To a certain extent, historical districts remain unchanged as times goes, in another word, they show us a picture of what the city looked like long times ago. With the development of the city and the changes in the way of life, several problems appeared in the historic district such as poor building quality and poor living environment. In my opinion, the spatial texture characteristics in historical districts are important factors affecting architectural function and living quality. Based on preserving the cultural value and community vitality of historical districts, the scientific analysis of the spatial texture of the districts is an effective way to improve the residential quality. In this paper, I use space syntax and ENVI-met software to analyze the spatial value and environmental value of Sanxue Street historical district. By integrating the spatial texture characteristics and microclimate characteristics of different regions in Sanxue Street historical district, I put forward several regional function suggestions and regional development directions to better protect and use this area.

Keywords: Historic district, spatial texture, spatial syntax, microclimate

Introduction

Historical and cultural area plays an important role in protecting cities’ historical and cultural memories, as well as showing cities cultural aspects. To a certain extent, they remain unchanged as times goes, in another word, they show us a picture of what the city looked like long times ago, therefore is valuable in our studies. However, it is questionable that if they can cope with the speed development of cities today. As there are giant changes in terms of social background, technology development as well as people’s habits of living, those areas have been criticized by the low quality of the buildings itself, and the poor living condition they are able to provide. We must take notice that those areas have kept quite several spatial texture characteristics. They, on one hand, are proves of the history itself, while on the other hand, it is questionable whether they are still able to satisfy the modern city live. Therefore, apart from affirmation the historical value of those areas, it is necessary to have scientific analysis at the same time and come out with remodel advices. By doing so, we are hoping to improve the living property of those areas, without sacrificing their historical and cultural values.

Both at home and abroad, the protection and renewal of historic districts is mainly concerned with the improvement of historical street scenes, the revitalization of neighbourhoods and the solutions to social problems. Which means that researchers often focus on the innovation of spiritual culture and the architectural space, but lack of the analysis within the spatial texture in the historical district. However, not only does the spatial texture contains the characteristics of the districts during the history, but also because the district is the core living space of the residents, the change of the spatial texture affects the quality of the lives of the residents. Therefore, by analysing the spatial texture of the historic district, and based on the transformation of space texture, we can put forward several suggestions.
for the development and protection of historical district. In my opinion, the spatial texture of historical district affects the spatial value and environmental value of the region. These two determines the development direction and potential of the surrounding areas and the quality of the district, which also affects the living quality of the region. Therefore, I propose a comprehensive analysis strategy of the spatial texture in historic districts, and an integrated value evaluation system for the spatial texture of historic blocks, which objectively evaluates the status of historic districts from different aspects. I take Sanxue Street historical district as an example to analyze spatial texture and propose protection strategies.

Analysis and evaluation of spatial texture in Sanxue Street historical district

With the development of the city, the district continues to build and transform itself: new areas continue to emerge, and old areas are gradually disappearing. Under the contradiction of urban development and replacement, the historical district is a witness and a microcosm of the development of the city. In the urban space category, space texture refers to the spatial relationship between different architectural combinations, including the arrangement and spatial scale. Spatial texture is one of the most important features of historical districts and cannot be ignored in the protection and reconstruction of the regions. The organization of inner spaces in historic districts determines the spatial texture of the block, as well as the function, the environment, and the residents living conditions. In the analysis of the space texture in historic districts, we focus on the space value and the environmental value.

Space value analysis of Sanxue Street historic district

In space value analysis of historic district, spatial syntax is a scientific and effective analytical method. Spatial syntax is an analysis method developed in recent years to study spatial relationships in different areas which can reveal the logical relationship between spaces. Different spatial forms and spatial relationships can affect different social activities. Through the quantitative calculation of the logical relationship between spaces, spatial syntactic can reflect the degree of correlation between spaces to a certain extent, and then analyze the relationship between human activities and space. The spatial syntactic analysis of historical districts is carried out to study the relationship between the different spatial texture of the area and the influence of the spatial relationship between different functions. And then we can make a rationalization proposal for the functional layout of the historical districts.

Present situation of Sanxue Street historical district

Sanxue Street historical district located inside the southern city wall of the old city of Xi’an. It covers an area of 11.65 hectares. The southwest corner of the district is near the Yongning Gate of the City Wall, and the southeast corner is near Wenchang Gate. On the east side of the district is the Wolong Temple and the Guanzhong Academy is on the west. Beilin history museum is also located here.

Sanxue Street historic district is east to the Baishulin street, the south side is Shuncheng South Road, the west side is the main commercial Street of Xi’an, and the north side is Dongmutoushi Road. The district is divided into two main regions. The eastern region basically retained the road pattern during the Ming Dynasties. In addition to the Beilin Historic Museum, most of the regions are residential areas. There are many commercial houses along the street. Most of the buildings in the district are from one to two floors, and most of them are Guanzhong style. The buildings in the district are chaotic and high density. There are few greenings in this region and there is no public activity place here. On the south side of the
western district is the Academy gate which is a cultural pedestrian street linking the Beilin Historic Museum to Guanzhong Academy. Both sides of the pedestrian street are mostly two storey buildings, retaining the architectural pattern of Guanzhong residential buildings and are mainly used as commercial areas. The north and west sides of the district are high-level commercial buildings.

![Figure 1. The region of Sanxue Street historic district](image1)

![Figure 2. The function analysis of Sanxue Street historic district](image2)

The development of spatial texture in historical districts is closely related to its own characteristics and geographical environment. In the historical development process, Sanxue Street historical district has maintained the pattern of "one temple, three schools" for a long time. "One temple" refers to the Confucian Temple, and "Three schools" refers to Xi'an government school, Xianning county school and Changan county school. Nowadays, roads in
the district basically maintain the patterns of the historical period, and the three north-south lanes relate to the Sanxue street on the south side. There are many historical buildings in the district, but most of the residential areas were renovated after 1970s.

**Analysis of spatial texture in Sanxue Street historic district**

When we study the texture of the block space, we can abstract the texture of the building into a two-dimensional map-bottom relationship. The space surrounded by the outer contour of the building serves as a “map”, and the space of the roads and squares serves as a “bottom”. When analysing the spatial texture of a street block, we often only do the function analysis for the part of the interior of the building and mostly focus on the spatial relationship and regional environment in the "bottom" part of the district.

Due to the difference in the construction age and the functions of the buildings, the spatial texture of Sanxue Street historic district presents different characteristics. As shown in the figure 3, most of the buildings in Area A are residential buildings, and some of them on the south side and west side are used as commercial areas. Most of the buildings in this area are one to two floors, and the architectural style retains the Guan Zhong style. Most of the buildings were built in the 1980s. The building density is very high, and the living space is rather narrow. The spatial texture of this area presents a dense and chaotic form. Most of the buildings in area B are two-storey commercial buildings with better quality and the architectural style also retains the Guan Zhong style. The spatial texture of the buildings in this area is a longitudinal enclosure pattern. Area C is a multi-storey residential area, and the building type is a slab type. The spatial texture of the buildings in this area is a horizontal bar pattern. Area D is a comprehensive commercial area with high building height and low building density. The spatial texture of the buildings in this area is homocentric squares pattern. Area E is a historic building protection area.

![Figure 3. Spatial texture analysis of Sanxue Street historic district](image)

**Spatial texture analysis by spatial syntax**

Space syntax is a spatial analysis method based on spatial topological morphology. It is a mathematical method for describing architectural space. Space syntax divides and reconstructs the space, and then use computer software to analyze syntactic variables and the spatial configuration. The basic principle of space syntax is spatial topology and visibility analysis which are both closely related to spatial recognition.
In the study of the spatial relationship between historical districts, the depth of sight is the core of spatial analysis. In space syntax, the spatial depth value represents the minimum number of steps needed to go from one basic area to another. Spatial depth in the district is a "measurement on the system", which changes with the connection form one space to another.

**Sight depth analysis of Sanxue Street historic district**

The spatial value of historical district is related to the spatial functions of blocks and the depth of sight. The visual integration value shows the calculated depth of sight in this area. If a space has a higher sight depth value, this space must have a better vision field. Red areas have higher sight depth value and you can see more spaces there. The result of sight depth analysis can guide the selection of functional categories in historical district. In general, commercial areas need more open spaces, and living spaces need more private spaces.

I conducted a sight depth analysis in different regions of Sanxue Street historic district. We can see from the figure that the sight depth value in the area A is relatively low which means the vision is restricted here. Although the privacy here is relatively good, but it lacks the connection with the outside world. The sight depth values in the area B and C are relatively high, where the spaces are open, and the scope of vision is relatively large. The sight depth value in the area D indicates that there is a certain privacy here, while still maintaining a certain connection with the outside. In summary, area B and area C are suitable for commercial district. area D is suitable for residential area, and area A should be appropriately reduced in building density as a residential area.

![Figure 4. Sight depth analysis of Sanxue Street historic district](Figure_4.png)

**Sight restriction analysis of Sanxue Street historic district**

For a certain area, if its nearby space boundary is very restricted to its own sight, then it will have very little to see. But when we go out of this area, we can see much more. On the contrary, if the space boundary near a certain area is weak in visual limitation there is a vast field of vision inside the region, and few new things will be found out of this area. The Visual Clustering Coefficient value describes the situation in which the region is restricted. When a region is more sight restricted, which means the value of the region is higher, the visual boundaries of its spatial boundaries are stronger. In the spatial texture analysis of historical
districts, we can evaluate the level of commercial value in this area through the results of sight restriction analysis.

I conducted a sight restriction analysis in different regions of Sanxue Street historic district. We can see from the figure that the sight restriction value within each zone is higher than the outside of the zone which means the boundaries of each areas are suitable for commercial activities. If we want to develop commerce in a certain area, we need to appropriately reduce the building density and increase the boundaries of the area.

![Figure 5. Sight restriction analysis of Sanxue Street historic district](image)

**Environment value analysis of Sanxue Street historic district**

When analysing the spatial texture of historical districts, the microclime in different spatial texture is an important factor for value analysis in the area. Because the microclimate in the district determines the value of the space environment in the area which directly affects the living environment of the residents. Making environmental analysis for historical districts is to find the potential microclimate and environment problems in the district, so as to provide the methods of improving the microclimate and environment of the region and then put forward suggestions for the protection and development of the historic districts. In the analysis of the microclimate and regional environment of the Sanxue Street historic district, I use ENVI-met software to simulate the microclimate in the region and I extract two representative climatic characteristics, including wind environment and thermal environment to analysis this typical area. ENVI-met is a kind of microclimate simulation software used by architectural planning and meteorologists at home and abroad. It has a high degree of agreement between simulation results and measured values, and can reflect the microclimate changes in the district to a certain extent.

**Climate characteristics of Xi'an**

Xi'an belongs to the warm temperate semi humid continental monsoon climate. Xi'an has four distinct seasons: it is hot and rainy in summer, cold and rainy in winter, and has more rainy weather in spring and autumn. The annual average temperature in Xi’an is around 13°C. July is the hottest month of the year, with an average monthly temperature of 26.1 to 26.3°C; January is the coldest month, and the average monthly temperature is -0.3 to -1.3°C. The amount of precipitation varies greatly between years, and the season distribution of
precipitation is also extremely uneven. 78% of the rainfall is concentrated in the period from May to October, and the rainfall from July to September accounts for 47% of the annual rainfall, and heavy rain appears. The annual average relative humidity is about 70%. The annual average wind speed is 1.8 m/s, and the prevailing wind direction is north-east wind throughout the year.

**Microclimate Analysis of Sanxue Street historic district**

The main function of the Sanxue Street historic district is divided into three parts: residential area, commercial area and historic preservation area. Each part has different requirements for the microclimate environment. For residential areas, residents’ pursuit higher quality of life has led to the need for improved microclimate and environment. However, in Sanxue Street historical district, the excessively high building density in the residential area and the messy architectural texture lead to a series of living environment problems. For the business district, moderate building density and a comfortable microclimate environment can attract more tourists. Due to the lack of accurate and large internal microclimate data of the Sanxue Street Historic District, this paper conducts microclimate analysis on historic districts through computer simulations.

![Figure 6. Summer wind speed simulation of Sanxue Street historic district](image)

![Figure 7. Winter wind speed simulation of Sanxue Street historic district](image)

I choose 10am on the typical meteorological day to simulate the wind speed in the district. From the simulation results of the summer wind speed we know that the wind speed in the block changes from 0.5 meters per second to 1.5 meters per second. The wind speed inside the residential area is relatively low, and the wind speed along the street is relatively high. Changes of the wind speed are basically irrelevant to the direction of the street. From
the winter wind speed simulation results, we can see that the wind speed in the area varies from 0.5 meters per second to 1.5 meters per second. The characteristics of wind speed change are reflected that both in residential areas and streets, the wind speed is relatively high in the east and west directions, and the wind speed is relatively low in the north and south directions.

We know that proper wind speed in the summer will help improve the comfort of the area. And in winter, people's comfort will decrease obviously with the increase of outdoor wind speed. In summer in the district, the wind speed in the streets and residential areas is relatively comfortable, and the wind speed changes slowly so the wind environment in the district is quite comfortable. In winter, the change of wind speed in the district is obvious and the wind speed is larger in the east and west directions and slower in the north and south directions. Therefore, I suggest planting evergreen trees on the streets in the east and west streets to improve the wind environment in winter streets.

It can be seen from the simulation results of summer temperature in Sanxue Street historic district that basically, the temperature in east area is higher than the west area. The temperature in the residential area is higher than that in the commercial area. The trend of temperature change is in line with the change of building density. The temperature is higher in the area with larger building density, and the temperature in the area with smaller building density is lower. In the area with similar building density, the change of temperature is mainly related to the distribution of greening. The temperature in the areas with more greening is lower, and the temperature in the areas with less greening is higher. The trend of temperature change in winter is similar to that in summer in this district.
Therefore, for residential areas, proper control of building density and increased greening are effective ways to reduce the outdoor temperature in summer.

It can be seen from the results of the summer relative humidity simulation that the changes in the humidity in the district generally present a trend that the southeast region is lower than the northwest region. The humidity in the residential area with higher building density is lower, and the humidity in the commercial area with lower building density is higher. From the winter relative humidity simulation results, we can see that the humidity change in the district generally shows the east side is lower than that in the west side. Because the east wind prevailed in Xi’an in winter, the humidity in the upwind area is lower than that in the leeward side.

In winter, when the relative humidity is large, it will accelerate the heat conduction and make people feel chilly. When the relative humidity is low, people will feel dry and easy to catch a cold. The most pleasant relative humidity in summer is 30% to 60%, and the best relative humidity in winter is 30% to 80%. From the simulation results, we can see that the relative humidity in summer is in the appropriate range, while the relative humidity in winter is higher than the appropriate range. Therefore, it is suggested to open up several East-West wind channels, strengthen the air circulation in the East and west directions in the blocks, and reduce the humidity on the east side of the block.

Conclusions
The problems in the spatial texture of the Sanxue Street historic district are mainly reflected in the excessive density of some residential areas and the lack of contact with the outside within the region. Some commercial areas are not open enough and lack of external interface. The problem of microclimate in the district is reflected in the decrease of comfort caused by the large wind speed in winter. It is suggested to increase the building texture of north south direction and increase the green plants in the appropriate area.

Figure 12. Regional Planning of Sanxue Street historic district

Through the analysis, I put forward suggestions for the development of three regions in Sanxue Street historic district. Areas A and B are mainly residential areas, adding commercial functions to their regional boundaries. Area C is a commercial area. It is suggested that Area A should reduce the building density and increase greening to improve the quality of living. It is suggested that Area B should increase greening in the East and west directions and increase the north-south direction building without changing the building density. It is recommended that Area C should properly reduce building density and expand the space boundary.

References


PUBLIC RECLAMATION OF BRIDGES, THE CAIRO CASE

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Abstract: The notion of city making, derived from the traditional top-down planning methods and predicting activities to occur in certain places designed to accommodate them, is insufficient to deal with the complexities of everyday life practices taking place in urban spaces. Citizens’ interventions that do not follow the planning regulations such as street vendors’ encroachments, appropriation of bridge’s sidewalks, and using spaces under bridges result in changes in the nature of public space accompanied by a wide range of grassroots struggles. The phenomenon of the unplanned use of public space known as insurgent public spaces is widely spread gaining tons of academic interest. It is crucial to understand the insurgent settings to achieve sustainable vibrant urban spaces. Cairo’s infrastructural networks, especially bridges, play a vital role in the struggles taken part by community to reclaim public space. The aim of the paper is to investigate the phenomenon of informal use of bridges as insurgent public spaces in Cairo. A conceptual framework drawing on the notion of insurgency and informality will be applied to the case study for analysis. The case study mainly comprises of qualitative data based on direct observations and interviews. In conclusion, we discuss the physical, economic, social, cultural, and legal aspects behind the emergence of these insurgent spaces.

Keywords: Insurgent public spaces, Bridges, Cairo

Introduction

Citizens’ interventions that change the nature of public spaces are important to activate a vibrant city life (Hou, 2012). In dense cities like Beijing, residents are appropriating residual spaces-busy street median strips, concrete areas between highway flyovers, parking lots, and sidewalks- to support their old habitats practicing taichi and dancing yangge (Chen, 2010). In Los Angeles, Latino residents are reshaping urban spaces to fit their needs, the Evergreen Cemetery jogging path shows the transformation of a deteriorated sidewalk surrounding a cemetery into a vibrant jogging path made of rubber, enhancing the neighbourhood quality of life (Rojas, 2010). The Shilin Night Market in Taipei, one of the largest and most popular evening markets in the city, known for its illegal vendors. Monitoring protocols and temporary storage sites were developed by vendors to escape police enforcement. When the policemen approach the market from a distance, they can easily detect them, signal each other, disappear in a matter of seconds, and then gather again once the police go away (Hou, 2010).

These interventions clarify the distinction between two types of public spaces-Institutional public space and insurgent public space. Institutional public spaces are those spaces designed by governments to accommodate certain predicted activities. These spaces include parks, streets, plazas, squares, and privatized public spaces, serving certain publics. On the contrary, insurgent public spaces are those spaces produced by citizens defying regulations. The phenomenon of the unplanned use of public space is widely spread gaining
tons of academic interest. It is crucial to understand the insurgent settings to achieve sustainable vibrant urban spaces (Hou, 2010).

The notion of city making, derived from the traditional top-down planning methods and predicting activities to occur in certain places designed to accommodate them as shown in Figure 1, is insufficient to deal with the complexities of everyday life practices taking place in urban spaces as shown in Figure 2 (Elsheshtawy, 2011). In planning literature, the shaping of urban spaces are not only limited to the decisions taken by governments and planners, but also by the everyday citizens using these spaces (Finn, 2014). According to Jon Lang in Urban Design: The American Experience:

“All kinds of people are involved in designing cities: lawyers, developers, individual households, and professional designers of various types. Much is designed by people who do not regard themselves as designers, but whose actions nonetheless change the built world. While professional designers are involved in making many decisions about the future of the city, many design acts are made by the citizens of cities on their own behalf.” (Lang, 1994, p. 35)

Cairo is known for its high density, suffering from the lack of public spaces (Mouad, 2013). Cairenes use urban spaces in an innovative way—“they turn a highway median into a playground for soccer game, any green area for a picnic, and a bridge’s sidewalk for almost anything” (Lababidi, 2007, p. 118). Cairo’s Neo-liberal policies are scaling back public services and encouraging the privatization of public goods. However, most Cairenes cannot afford the effects of such policies (Singerman, 2009). The focus of restructuring Cairo on elite consumption patterns, results in excluding the majority of its residents. As a result of
this exclusion, Cairenes lose basic control over their daily lives. Cairo is turning into an “increasingly segregated city” where this unfortunate marginalized majority suffer. It is crucial to fight “neo-liberal dispossession” that prevents social equity and urban harmony in a more creative way (Naguib, 2010).

This paper aims thus to investigate the phenomenon of informal use of bridges as insurgent public space in Cairo. The first part of the paper investigates the definition of insurgent public space in theory, then the insurgencies taking place on Nile bridges were identified and analysed through a case study of one of these bridges to find out the reason behind the emergence of such activities. Finally, the government response to these informal activities was discovered.

**Insurgent Public Space**

Public space is defined as “all areas that are open and accessible to all members of the public in a society in principle, though not necessarily in practice” (Neal, 2010, p. 1). The decline of public space accessibility is a major issue in many discussions. But there is continuous redefinition as well as expansion to the notion of the publics—people who can access public spaces—so “public space is gained, not lost”, (Neal, 2010, p. 203). The Classical Greek Agora is a good example to illustrate this point, as it was only accessible to certain publics. But over time it ends up available to the marginalized publics as they become accepted as legitimate members (Neal, 2010).

The traditional way of using public space is ignored by people accompanied by the emergence of unpredicted activities in certain spaces that are not designed to accommodate them. In cities around the world, the utilization of public space becomes unusual and unconventional, urban sites are widely occupied with temporary and informal gatherings (Hou, 2010). As stated by (Watson, 2006, p. 7), “Public space is always in some sense, in a state of emergence, never complete and always contested.” The phenomenon of the unplanned use of public space known as insurgent public spaces is widely spread gaining tons of academic interest (Hou, 2010). Informality is not a new topic in urban studies but such interest brings up the question concerning the reason behind the prevalence of this activity at this particular time (Elsheshtawy, 2011).

Nowadays, the urban structure is controlled by Neoliberal systems. The urbanization of the rural parts of the countries as well as the increasing number of the moving population to urban areas is taking place within and between nations (Macera et al, 2013). In neoliberal systems, the exclusion of the citizens that are not “good-paying customers” takes place due to the privatization of the city’s infrastructures and urban spaces. The reason behind the prevalence of urban insurgencies in cities around the world is the dominance of neo-liberal systems that ignores citizen’s needs and rights (Miraftab et al, 2005).

The unpredictable response used by the marginalized citizens against exclusion from the system, creates an “insurgent citizenship”, the term insurgent is used to focus on the opposition to the idea that “the state is the only legitimate source of citizenship rights, meanings, and practices”, (Holston, 1998, p. 38).

The idea of “the right to the city” developed by Henri Lefebvre, is captured by what he describes as the oeuvre. The city as oeuvre focuses on the notion of city and urban spaces as an innovative outcome of and setting for the inhabitants’ everyday life. According to Lefebvre, there are two components of the Right to the City which are the right to appropriation, and the right to participation (Purcell, 2003). As indicated by Margret Crawford’s assessment of Lefebvre’s work, citizenship is characterized by the inclusion of all
the inhabitants’ appropriations and owns two essential rights: the right to participation and the right to appropriation. Participation enables inhabitants to take decisions concerning the production of urban spaces, while appropriation enables them to utilize urban spaces and produce new spaces that fit their needs (Bela, 2014).

The concept of insurgent public space owes to the idea of insurgent citizenship. As insurgent citizenship disagrees with the idea that the meanings and rights of citizenship are only legitimized by the state, the insurgent public space contraindicts the type of public space that is only managed and controlled by the state (Hou, 2010). Lefebvre explains that the production process of urban spaces includes trialectial expressions: conceptions, perceptions, and lived experience. The conceptions are the use of urban space as predicted by the urban authorities, cannot be totally controlled as Urban spaces are constantly accessible for appropriation. The impossible control of orderly used public space results in a gap that allows for the prevalence of urban insurgencies (Iveson, 2013). The prevalence of such uses makes public space more open and inclusive. Therefore, actions, contestations, and struggles are considered as the main components that shape public spaces. The reshaping of public space is affected by the complex power geometries including the attempts of different actors to decide “who and what the city is for" (Iveson, 2013).

“Urban protests” include two different types. The first one covers loud, crying revolutions and strikes, while the second one covers the process of “slow encroachment” that takes place in many cities, challenging the top-down planning paradigm. This process begins with the release of unplanned settings by marginalized communities, such as informal markets and street vendors (Nagati et al, 2013).

A set of “micro-spatial urban practices” seeking to reconfigure the nature of urban spaces in many cities, such as appropriating vacant lots, utilizing spaces under bridges; are widely spread in many cities around the world; and are linked under variety of titles such as insurgent, guerrilla, do-it-yourself, participatory, grassroots, and everyday urbanism (Iveson, 2013). These practices show up in variety of publications that are focusing on citizens’ interventions that reshape the relationship between citizens and authorities (Elsheshtawy, 2011). In spite the fact that these practices might not appear as an insurgency, but it is crucial to know that they are accompanied with lots of grassroots struggle to gain possibility (Hou, 2010). However, in order to achieve sustainable vibrant urban spaces, it is crucial to study the informal settings and to realize the significance of urban environments in providing a framework that shows the unplanned activities (Elsheshtawy, 2011).

These unplanned activities indicate the existence of a particular need in a community and at the same time trying to fulfil that need (Pagano, 2013). Community acceptance of these activities is affected by the nature of space used whether the space is contested or not, and by the usefulness of these activities such as urban gardens and street furniture providing a place to sit (Pagano, 2013). Skateboarding faces general community opposition, as it causes noise and damages in public spaces, but it only found acceptance under a freeway overpass, as this space is uncontested. There is a relationship between community acceptance and the legality of these activities, as illegal acts that are widely accepted by communities, can gain legality (Pagano, 2013). The 'Mediaspree Project' in Berlin is used as an example to explain this point; the spree is a river that flows through Berlin. The riverbanks offer an investment opportunity, so Berlin government aims to make use of it by selling the riverbanks to foreign and German investors, but it faced public opposition. A strip of the riverbank was occupied immediately to turn into an informal public space. At first they came into conflict with the government, but after they gained the support of the green
party, a distance of 10-50m along the riverbank was kept as legal public space (Elsheshtawy, 2011).

The government response to these interventions takes many forms. Some interventions are not recognized by the government, others are either accompanied with official sanction or gain support and legality (Finn, 2014). Some examples are discussed to help investigate this process and show how the reclaimed spaces have been integrated back into the city. In Cairo, marginalized communities in informal areas surrounding the Ring Road were excluded from accessing it. So, communities started to construct small stairways to get access points onto the Ring Road, this led to the emergence of some interventions at these points such as microbus stations, roadside tea-stands, and coffee shops. But the most informal intervention that appeared was the Mu’tamedeya exit, as the local community documented the construction process of the exit in a video, and they sent it to the governor with a request to inaugurate it. The governorate accepted this initiative and accepted the exit as a part of the city’s infrastructure (Nagati et al, 2013).

These insurgent spaces occur in each city. Each of these spaces displays a distinctive cultural, social, physical, and economic need, from which the marginalized communities are deprived of. The case study from Cairo that follows will bring forth the aspects behind the emergence of such spaces, and their role in shaping the urban spaces.

![Figure 3: The developed framework, source: Authors](image-url)
Tools and Methods

The first part of the paper investigates the definition of insurgent public space in theory; the developed framework as shown in Figure 3 had been applied to the case study for analysis. It was necessary to study the phenomenon of insurgent public space within its real life context to understand the complex grassroots actions taking place between community and authorities. The case study research method is used to investigate this phenomenon. Al Gama’aa Bridge in Cairo is chosen as a case study for analysis as it is a liveable bridge containing diversity of uses and users. The qualitative data are collected through direct observations and interviews with vendors, and the bridge’s users. The activities occurring on the bridge’s sidewalk were documented using an activity map; coloured symbols are used to represent types of activities. A part of the bridge has been observed on Thursdays of July from 7:00 pm to 11:00 pm as shown in Figure 4; the selected sector of the study includes all types of activities occurring on the bridge.

People using the bridge were asked about the distance to their homes, their use patterns, their reasons for using the space, and how often do they use the bridge and if they come into conflict with the vendors. While the vendors were asked about whether they get permission by local authorities, if they come into conflict with the municipality and if there is a legal action planned in the future to stop these activities, and whether they come into conflict with people using the bridge.

Figure 4: shows the selected sector for analysis, source: Google Earth.

Cairo Riverfront and Marginality

“The Nile defines Egypt: without it, life couldn’t thrive. Cairo’s strategic existence is due to the Nile”, (Lababidi, 2007, p. 119). Over the past few decades, the privatization of the riverfront has been significant, cutting off the free public accessibility to the Nile. Most of the riverbanks have been occupied by various kinds of syndicates, some governmental agencies, private clubs, cafeterias, and restaurants, as well as the congested roads along the riverbanks. The riverfront becomes a space where only members of the syndicates or agencies or people who can afford the private sites are allowed to use (Gabr, 2004). In turn, the majority of the general public were separated physically, symbolically, and visually from the Nile. It is one of our rights as dwellers of this country to enjoy our Nile without paying for it.
However, the limited spaces that are left for the public to use are not adequately developed as these spaces lack proper seating areas, shade, lighting, maintenance and most of them are fenced off with the green metal barriers. So, these spaces are deteriorated and not inviting as shown in Figure 5. In response, Cairo’s marginalized communities are reclaiming their rights to use public spaces by making interventions such as appropriating urban spaces to satisfy their economic, cultural, and social needs. These interventions change the nature of public space and constitute new relationship between the city and its inhabitants (Nagati et al, 2013).

![Figure 5: The current state of the riverbank, source: Authors](image)

The existence of the Nile is accompanied by a challenge to control it and to cross it. Simple ferryboats were used at first as a means of transportation from bank to bank, but now “ten bridges span the Nile in Cairo” (Lababidi, 2007). The informal use of the bridge sidewalk was the best alternative for people who want to enjoy the riverfront (Nassar et al, 2013). The neglected marginalized group of society has taken over the space transforming it to satisfy their needs for leisure, entertainment, and nature appreciation. Many activities have emerged on the bridge including walking, sitting, viewing the river, exercising, fishing, celebrating weddings, and vending. When approaching the bridge, it is full of life and activities. The usual scene on the bridge is the street vendors who set plastic chairs, servicing cheap food and drinks.

The life of public spaces is significantly needed and appreciated by Cairenes. However, the public accessibility of urban spaces is very limited due to different aspects which are the “scarcity of urban spaces” and the regulations or socio-economic segregation that prevents
the majority from using many places. These aspects are rooted in the history of the city. Consequently, “Cairenes reclaimed their own public spaces” (Abdelwahab, 2013); For example, a web blog about the city describes:

“One of the things that I love about Cairo is the way Cairenes take over the Nile bridges at holidays and festivals, sometimes to the virtual exclusion of vehicular traffic. It’s reclamation of network space”

‘Al Gama’a’ Bridge: a local insurgent space in Cairo

Al Gama’a’ Bridge (University bridge) is one of the ten bridges that span the Nile in Cairo, opened a passageway from Roda to Giza, leading to Cairo University. The bridge offers a magnificent view of the River Nile; a proper sidewalk width of approximately 5m that allow the occurrence of such activities. Here, the bridge’s sidewalks are used in unintended ways all the year especially on Thursdays, Fridays, and Sundays; the majority of the users belong to the lower and middle income group. The activities occurring on the bridge’s sidewalk were documented using an activity map as shown in Figure 6.

Just after the sunset, vendor’s carts occupy the sidewalks; they are located at fixed locations approximately at equal distance in front of a light post from which they get electricity, lining up their colourful plastic chairs, inviting people to sit and serve them with affordable food and drinks, playing folk music. These vendors took over Nile bridge spaces. Another type of vendors appear with moveable carts serving people with sweet potatoes, corn, and tirmis (lupine seed) searching for the best space, but it’s first come, first serve. There are considerable numbers of pedestrian using the bridge. At the ends of the bridge, a large number of men that come for fishing with their fishing gears spend hours chatting together, waiting for a catch. Besides the fishermen, there are also those people leaning against the rail who come to the bridge alone or with family and friends to enjoy the Nile view. Moreover, The Bridge is popular with wedding celebrations, at this time; you find the bridge congested with cars, microbuses, and motorcycle of family and friends, accompanied by a honking sound, according to the description of (Lababidi, 2007, pp. 118-119):

“On Thursdays and Sundays in particular a rhythmic honking proclaims the advancing nuptials; adorned with flowers and ribbons, the cars swerve to a stop, doors are flung wide open, and the trilling sounds of the zaghruta announce the arrival of the bride and groom. Cameras flash, recording the happiest day above the Nile’s fertile waters.”

Some couples celebrate their wedding only on the bridge as they can’t afford to pay for a wedding hall; while others only come to take some photos, then continue celebration in a wedding hall. At this spot, a group of people surrounding the bride and groom are singing traditional wedding songs.

Afterwards, the bridge is empty by three in the morning, loading the chairs into vans and pushing the food carts home. The University Bridge occupies a significant position in the collective memory of Cairenes. People love the place; they come from different areas just to enjoy the view. The bridge is conceived as a transport facility, but it is lived and perceived not just as a facility but also as a social and economic space.
Thursday 7:00pm to 11:00pm

Families are sitting watching the view of the Nile, eating and drinking, having conversations.

Vendors with moveable carts are serving people with sweet potatoes, corn, cotton candy, and tirmis (lupine seed).

Microbuses dropping off people who come to celebrate the wedding, parking along the sidewalk.

People gather to celebrate a wedding, singing traditional wedding songs.

The ends of the bridge are always occupied with fishermen, parents come to enjoy the view and let their children play, and people leaning against the rail to enjoy the view.

Women buying some drinks before leaning against the rail.

Figure 6: Activity map showing activities taking place on the bridge sidewalk, source: Authors
**The Response**

When asking the public why they use these spaces, most of them said that they cannot afford the spaces on the riverfront, others said that they come for the breeze and the view, and a bridal couple said that they came to celebrate and take photos as they cannot afford to pay for a wedding hall. By asking them about their acceptance to the vendors, most of them replied that the vendors are friendly providing them with food and drinks. Some people complained that sometimes the government does not allow them to park their cars on the bridge. In this case, the uncontested nature of the bridge sidewalk as well as the utilization of space provide the public with different services such as sitting areas, food, and drinks; lead to the community acceptance of such acts. One of the vendors says that “our presence makes the space more vital and safe for public use, without our presence, it will turn into a dead space where people might get robbed.”

Vendors manage the space, putting their carts in specific locations, which they have been using since approximately twenty years. Each vendor knows his space, marking his territoriality with his cart and the plastic chairs, which nobody can surpass. Asking the vendors about the government response, they said that “every now and then the police officers approach the bridge to confiscate our possessions. So we are obliged either to pay penalty to get our possessions back or to go and buy another one.” In both cases “we come back to complete our operations again.” They said that these spaces are their source of income. These spaces prove that public spaces in Cairo are in continuous state of emergence, contradicting the type of public space that is only managed and regulated by the government. The struggles over public space are significantly contributing in the making of public spaces in Cairo.

**Conclusion**

Informality plays a crucial role in shaping urban spaces in Cairo. The privatization of most of the riverfronts to restaurants, hotels, and clubs for professional syndicates prevents the majority from enjoying the Nile. Accordingly the riverfront becomes a space where only members of the syndicates and agencies or people who can afford the private sites are allowed to use, creating a large number of marginalized communities having different needs and rights. Accordingly, the informal use of Nile bridges was the best alternative for people to enjoy the Nile due to several aspects including the uncontested nature of the space, space potentials providing a continuous sidewalk with proper width and magnificent view, and different services provided by illegal vendors. Mostly lower and middle income groups are reclaiming their right to use the bridge’s sidewalk as a recreational public space; it is also used by vendors as an income source to protect their livelihood. High volume of folk songs, the way people celebrate their weddings expresses the culture of the users.

The bridge sidewalk is converted into a vibrant urban space full of life and activities, so the urban space is utilized in multiple ways besides the single designated use it was conceived for. When analysing the University Bridge as a local insurgent public space in Cairo, different aspects were found behind the emergence of such actions as shown in Figure 7. These actions can be considered as forms of insurgence against the status quo that ignores public’s needs and rights. These spaces face opposition from the government but at the same time the government failed to prevent the occurrence of these spaces. Despite the fact that these spaces are illegal, these everyday life spaces shape the city more than formal design and official plans. Egyptian governance structures weaken but don’t stop
the public’s role in the remaking of their cities (Singerman, 2009). Although these spaces are illegal, it fulfilled the ignored economic, social, and cultural needs of the marginalized community.

It’s better to start accepting and legalizing these spaces and stop refusing and criminalizing them. As these spaces are in a state of continuous emergence as long as no proper solution or alternative is found. In order to achieve a sustainable urban environment, the focus of government and planners must be turned to the crucial role of the marginalized citizens in shaping the urban space to fit their needs. Citizens must gain the right to decide how urban spaces can be used or modified. These spaces are critical in maintaining liveable and healthy cities.

Figure 7: Aspects behind the emergence of insurgent spaces on Nile Bridges, source: Authors.

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Abstract: The paper concentrates on tools and technologies used for participatory processes in the context of sustainable urban planning and design. The paper aim is to explore and present how some recent tools and technologies are used to inform policies, strategies or overarching concepts for engaging stakeholders to work toward a common vision for change in their community. The capabilities of Scotland’s Place Standard tool, BREEAM-Communities assessment tool and the Smart City technologies that enable co-production in urban planning and design are analysed through literature review.

The Akitivniy Grazhdanin, a citizen engagement portal was established to devolve decision-making on aspects of Moscow’s smart city programme to citizens, provides a case study on the potential use of Smart City technologies to solicit citizens’ views on the city management and transformation.

The paper discusses the impact of those tools and technologies in terms of supporting place-based collaboration, citizen engagement and participation, and their value to providing for an open and iterative design process. The research highlights the strengths and weaknesses of the analysed tools and technologies. In conclusion the paper makes recommendations as to how frameworks can best be shaped by such tools in order to achieve local ownership, and provide structure to a more inclusive development and sustainable urban design. Finally, the paper gives a high-level indication as to the next stage of planned research.

Key words: social innovation frameworks, engagement tools, smart city technologies

Introduction

Across the developed world, behaviours to govern actors involved in spatial development in order to safeguard public assets and community cohesion have changed (Wainwright, 2014). Often planners have sought solutions to society's ills - poverty and ill-health - through the development process, placing their faith in the bricks and mortar of buildings (Jacobs, 1961), sometimes ignoring the root causes of social deprivation in order to respond to shifting short-termist public policy context at the time of urban development planning (Finger, 2018; Greenfield, 2017). Sustainable urban planning and design are increasingly dependent on social innovation, a term given to a variety of methodologies, tools and processes that support a multidisciplinary approach to urban transformation. By definition, social innovation is something that is collaborative - meaning that it requires input from a number of (often isolated) actors, sectors, domains or knowledge areas working together towards a common goal. Taking a hypothesis that social innovation occurs over phases of the network, framework and architecture (Horgan and Dimitrijevic, 2018), this paper examines how collective approaches to urban design can inform more holistic policy development and inclusive growth. The idea of social innovation, defined as novel ideas that meet a social challenge (Manzini, 2014; Murray et al, 2010), can help us look outside of the established, sometimes restricted domains of single professions. Bria (2015) conducted a far-reaching study to extensively document global social innovation initiatives, concluding that while there is an ever-increasing transdisciplinary movement of actors across technology and civil society...
collaborating on solutions to social challenges, more needs to be done to coordinate these actions and understand their implication for policy making and urban development.

Already two decades ago, discourse on sustainability in urban planning and design has brought into question the notion of adaptation for sustainability by asking whether we should be trying to sustain a status quo in situations or scenarios were the established modus operandi is no longer ‘fit for purpose’ (Marcuse, 1998). This is particularly relevant in the field of the built environment, given the lack of innovation in design, practice and materiality (Johar, n.d.) and the fact that the construction industry remains the biggest global polluter after agriculture (Circle Economy and ABN AMRO, 2017). To support the internationally agreed UN Sustainable Development Goals (SDGs) (United Nations, 2015), new holistic models – frameworks consisting of focused policies and local structures - are required to assist co-production of scalable solutions that can be open and agile enough to generate ownership amongst a diverse group of stakeholders - evoking alternative pathways to urban development.

A networked based approach (Monbiot, 2017) is novel in the way that it makes best use out of pools of common resource, knowledge and experience - and uses advancements in technology to channel knowledge exchange, distributed decision-making and governance (Kitchin 2018; 2014). In an empirical investigation of social innovation initiatives for sustainable urban development, Angelidou and Psaltoglou (2017:115) found the link between social innovation and sustainable development to be “very pronounced” owing to the challenges that contemporary urban settlements face and their position as “places where urban futures and the knowledge and innovation economy come together”. Their investigation puts social innovation for sustainable urban development in two “clusters of literature”, one concerned with “the role of citizens and their communities” and a second one concerned with “socio-technical transitions, focusing on the process and involved actors in social innovation” (Angelidou and Psaltoglou, 2017:115). They identified four types of citizen profiles in the sustainability discourse: the ‘citizen sensor’, the ‘sharing citizen’, ‘the collaborative citizen’ and ‘the entrepreneurial citizen”, were citizens can have dual or multiple roles “depending on the situation” (Angelidou and Psaltoglou, 2017:122).

The global financial crisis in 2008 has acted as a driver of the relentless pace of technological innovation were the low costs of computing hardware has given rise to ubiquitous technology - with sensors and data collectors embedded across our public realm and private spaces creating an ‘Internet of Things’ (Greenfield, 2017; Ash et al, 2018; Kitchin, 2018; 2014). The increased capabilities to collect data have given rise to the era of Big Data (Kitchin, 2014) where complex data sets, comprising information modelled from new data sources, converge to produce a sophisticated real-time evidence base for decision-making (Kitchin, 2018). Technology-led, big-data approaches to city management often fall under the domain of the smart city, a paradigm that has emerged in the past decade as an umbrella term for seeing technology as a panacea to right the intractable problems of society (Greenfield, 2017; Hollands, 2008).
Contemporary approaches to sustainable urban planning and design recognise the importance of developing place-based frameworks for development that take holistic social, economic and environmental factors into consideration. A framework, in the context of this paper, encompasses the policy and the structures that may enable sustainable community (renewal) transformation to take place. Such frameworks are needed because for too long, many in the built environment professions - motivated by questionable ethical positions - have worked too closely with commercial actors, facilitating unsustainable development that has exacerbated inequality and encouraged rampant gentrification (Hollands, 2008). In recent years this close relationship, between architects and developers in particular has left many questioning the role of the contemporary architect and their value to modern society (Wainwright, 2014). Over the decades, participatory design in architecture has often been tokenistic, or occurring too late in the design phase to affect decisions that impact communities (Oliver and Pearl, 2018). Authorities and local governments have often produced plans or strategies that focus exclusively on economic growth as a pathway out of inequity, working towards KPIs and quantitative outcomes that mask multiple indices of social deprivation and structural poverty that cause communities to decline and require regeneration (Greenfield, 2017). Planners are destined to repeat the mistakes of the past - slum clearances that produce peripheral ghettos - without a set of new tools and processes that can help them work towards new collective social outcomes, common across a whole ecosystem of community agencies.

The impacts of globalisation - and the inequitable relationships between richer and poorer actors - are manifest in environmental, economic and social shocks experienced by communities worldwide. This investigation, which takes a global perspective, follows an ethnographic action research approach, engaging communities in participatory dialogue to build up a deeper understanding of the context for resilience. Research includes a number of international case studies from developed economies to the developing world and the global south, seeking to map commonalities in strategy and approach to adaptation. Cases have been selected based on their capacity for networked collaboration to develop open and agile frameworks for resilience planning. The case of Moscow, looks at how the smart city paradigm can provide an overarching mechanism to facilitate wider participation in urban development and change. The hypothesis that underpins this paper centres on three distinct phases of social innovation - network, framework and architecture - connected by feedback loops. Pathways towards developing frameworks for place-based decision-making are investigated by examining tools and technologies that have been used by community networks, local councils and other governance agencies, and the potential use of Smart City concept for participatory decision-making about urban development. Along with the literature review, a case study is included on Akitivniy Grazhdanin, a citizen engagement portal established to devolve decision-making on aspects of Moscow’s development to citizens. The case study has been developed through action research, an ethnographic investigation alongside a literature review.
Tools and mechanisms used in place-based frameworks

**Scotland’s Place Standard Engagement Tool**

UN Sustainable Development Goals (SDGs) (UN, 2015) are translated into overarching national policies used by local agencies to develop specific targeted and contextual local development strategies. In the case of Scotland, the UN SDGs have informed Scotland’s SDGs (Scottish Council for Voluntary Organisations, 2018), expressed as vision statements in Scotland’s National Outcomes (Scottish Government, 2018) and Scotland’s Third National Planning Framework (Scottish Government, 2014). These policies are supported by legislation under the Scottish Government’s Public Engagement and Consultation, Community Empowerment Scotland Act (2015) (Scottish Government, 2015) and set against National Standards for Community Engagement (Scottish Government, 2016) which mandate a level of community engagement and participation on development projects. In response, tools such as the Place Standard have emerged as a method to engage citizens to assess their settlements and prioritise local goals aligned to overarching global and national sustainable development policies.

The Place Standard tool, developed with planners and architects in Scotland, “lets communities, public agencies, voluntary groups and others find those aspects of a place that need to be targeted to improve people’s health, wellbeing and quality of life” (Place Standard). It provides “a simple framework to structure conversations about place” and takes a long-term view of sustainability, encompassing a number of domains - including local economy, public transport, housing - allowing distinct and separate organisations to work together productively. Along with economic and spatial aspects, it has been designed to consider social aspects - health, welfare, work and community.

The tool prompts discussion among stakeholders, helping to identify assets and resources within a community as well as challenges and areas for improvement. In Scotland, communities who are seeking to embark on a journey of regeneration or physical improvement are encouraged to use the Place Standard, often with the support of Planning Aid Scotland through workshops and charrettes (Planning Aid Scotland). By using the tool to interrogate project outcomes, development proposals are ideally more balanced, achieve community buy-in and generate ownership among stakeholders, resulting in a local development plan (LDP) - framework – once shared outcomes have been agreed in terms of a development approach. In this way, the Place Standard tool is part of a process, and not an end in itself. A report in 2017 listed 65 separate instances of Place Standard being used across Scotland between December 2015 and February 2017 - reaching over 11,000 citizens across 22 local authorities (Scottish Government, 2017). Overall the tool has been well-received as an aid in aligning ambitions within a community ecosystem, particularly within the context of community engagement, owing to its universality and ease of use. The report found that aligning the engagement process to strategic decision-making achieved most buy-in from stakeholders (Scottish Government, 2017).
This said however, as a tool with which to organise strategic actions, it requires further refinement. Managing and organising respondents’ data can be resource intensive and ambiguity arises when using the tool over roles and responsibilities for individuals and organisations in taking forward actions (Scottish Government, 2017). A significant challenge identified through the Scottish Government evaluation was to ensure community engagement is representative of the whole population in a place and that future efforts seek to support engagement with those who are most marginalised and under-represented as a precursor for reducing inequality and promoting inclusive growth (Scottish Government, 2017).

**BREEAM-Communities Assessment Tool**

Building Research Establishment (BRE) has developed BREEAM-Communities (BREEAM-C) as a development assessment tool to help developers and private sector stakeholders to take sustainability concerns into account. It contains a compulsory consultation component in order to ensure the "needs, ideas and knowledge" of communities are taken into account during the detailed planning stage of a development (BRE, 2012). Community participation in BREEAM-C is required to certify the master planning process (Oliver and Pearl, 2018; BRE, 2012). The tool defines a number of domains and sets of indicators in order to assess the quality of design in terms of the social, economic and environmental impacts of development on a community. BREEAM-C, however, is primarily envisaged to help a design team engage with sustainability issues in the early design phase of a development project.

Oliver and Pearl (2018) looked at how the BREEAM-C tool was used by the developer of a large mixed-use new build project at Masthusen in the Swedish city of Malmö, focusing on its role in facilitating community consultation and participation. The study found the tool to be limited, "as a certification tool used solely by the developer, as opposed to a tool that could bring together the City of Malmö, community groups and the developer in a synergistic project" meaning that it was "limited to focusing on achieving sustainability outcomes within the boundaries of its site" (Oliver and Pearl, 2018:PAGE). The study found that the tool, which focuses on product outcomes in the design process, “had a limited impact on empowering the immediate and surrounding communities and creating a synergistic, integrated design with its surroundings" (Oliver and Pearl, 2018:PAGE). This was owing to the fact that tool was said to employ a "limited definition of community", and was employed too late in the process, meaning that consultation had no impact on the design (Oliver and Pearl, 2018:PAGE). These observations point to the need to engage communities early in the design process – with community focused tools like the Place Standard, and to use these to facilitate a common vision or strategic mechanism for development across an ecosystem of competing stakeholder positions (developer, local government and community).

**The Smart City Collaboration Mechanisms: Approaches and concerns**

The Smart City concept emerged in the early 2000s as a means for collecting data by using sensors, Information and Communication Technologies (ICT) and Internet of Things platforms...
that can inform better management of cities’ services. It has been aggressively marketed by technology companies to cash-strapped city governments since the financial crash in 2008 (Greenfield, 2017; Kitchin, 2015; Kitcin et al, 2015; Hollands, 2015; 2008). While there is no agreed discrete definition as to what the concept refers to exactly (Angelidou et al, 2017), there is a broad consensus that a smart city uses innovation in ICT as a means for achieving sustainable development, social innovation and improvement (Angelidou et al, 2017). Taking a systems-thinking approach to the Smart City, Caputo and Evangelista (2018) highlight that the Smart City depends on two main factors: “continuously updated Big Data and Smart Technologies” and “customer willingness to cooperate on their development”.

At an international policy level, environmental sustainability concerns are integral to the concept of the Smart City (Angelidou et al, 2017; Angelidou and Psaltoglou, 2017; European Commission) with many interventions focused on air quality and cleaner energy or transport solutions. Smart City solutions are adopted by many cities across the world as mechanisms for delivering community resilience through a focus on holistic social, economic and environmental outcomes (Angelidou et al, 2017). The Smart City provides a lens for looking at the city as a system (Saviano et al, 2016) on which to model scenarios and policy interventions; prototype and test new solutions; and deliver new social infrastructure.

Concerns regarding the Smart City paradigm as a key concept for sustainable development include questioning the motivation of global high-technology companies seeking partnerships with city governments (Hollands, 2008) and highlighting the dangers of seeing technology as a panacea to all ill-gotten urban problems (Hollands, 2015). Hollands (2015) refers to the work of Harvey (1989) and asks why the Smart City that is being promoted “can only be effectively delivered through a corporate vision of smartness, in conjunction with an entrepreneurial form of urban governance”, shining light on the absence in urban sociology of “an alternative to the neo-liberal city, smart or otherwise” (Hollands, 2015:62), and highlighting the need for a “substantial shift in power from corporate business and entrepreneurial city leaders to ordinary people and communities” (Hollands, 2015:63).

The concept continues to be a significant means for informing better urban management and development, with research indicating about 250 smart city projects worldwide (Navigant Research, 2017) and figures from the European Commission suggesting 240 smart cities with populations over 100,000 (Euractiv). While ambitions remain high, concerns are mounting. Kitchin (2014) identifies five main concerns, particularly over the politics of data collection and data use; technocratic city governance and development; procurement and investment in technology and infrastructure; technological performance and security and how the city is viewed as a system. He sees engagement and participation with stakeholders as a way to counteract the emergence of a “panoptic city”, and highlights that “without critical interrogations the smart cities of the future will likely reflect narrow corporate and state visions, rather than the desires of wider society” (Kitchin 2014:12).

Angelidou and Psaltoglou’s (2017) analysis of nine smart city case studies leads to similar conclusions. Angelidou et al. (2017:80) found that corporate smart city visions are “increasingly driven by business imperatives”, often misaligned with citizens’ priorities -
facing opposition from the local population in the case of Barcelona and Songdo (Angelidou et al, 2017; March and Ribera-Fumaz, 2016). Looking to research from Luque-Ayala and Marvin and (2013), Angelidou et al (2017:80) found that corporate initiatives “fail to develop the capacity of a city’s people to actually learn and deeply engage in the smart city discourse resource” and that “citizen uptake and stakeholder resonance is critical... as citizens need not only be informed, but actively engaged in the co-design of the smart city solution” (Angelidou et al, 2017:88).

Viewing the criticisms by Kitchin (2014) and Angelidou et al (2017) alongside others, questions that persist regarding the Smart City concern relationships between stakeholders - public, private and community actors in the pursuit of what Kitchin (2014) refers to as ‘smart urbanism’ and include:

- **Ownership** - Who owns the (Big) data, proprietary softwares, innovation and strategy within the ecosystem?
- **Governance** - What roles, responsibilities, process and protocols are in place to facilitate collaboration and partnership?
- **Participation** - What is the quality of public engagement and how does it improve democratic decision making (around sustainable urban development)?

The above questions have been used in the case study presented below.

**Case study: Aktivniy Grazhdanin and decision-making in Moscow, Russian Federation**

The use of smart city technologies in Moscow provides a case study on an information-led mechanism for enabling citizens’ participation in decision-making in city management, urban planning and design. Action research – live semi-structured interviews with citizens in Moscow alongside conversations through internet channels and online groups inform this investigation. *Aktivniy Grazhdanin* (AG, Active Citizen) is a tool developed by the Moscow Smart City team to engage citizens around urban development proposals and change in their city. The platform facilitates citizen oversight and participation in planning decisions, primarily on issues relating to the upgrade of the public realm and public spaces, as well as getting feedback on local government proposals on smart city strategies and development policies. Developed to offset a top down approach to city planning, over 2,000,000 citizens have participated, representing between 10 and 20% of Moscow citizens (Holder, 2017).

Moscow is currently undergoing a large-scale programme of *renovatsiya* – or renovation – where poorly performing buildings are due to be demolished in favour of improved housing projects to be built on the periphery of the city (Alonso, 2018), which is set to affect more than two million citizens in Moscow over the next fifteen years (Holder, 2017). The theme of renovation is of great concern to a great many of citizens in Moscow, where private ownership is high owing to the change in economic systems (Krasheninnokov, 2003).

**Ownership**
A majority of voting on AG takes place on the web platform, or mobile web application, yet there is also the possibility for informed citizens to vote at a Moy Dokumenti (My Documents), local public services centre in person. The “Our City” urban repair and development functionality has successfully engaged many citizens to use the platform (Murawski, 2018), part of which allows citizens to submit complaints relating to urban environmental issues. A consistent feedback loop where issues are responded to by the local government within a fixed time period of five days, results in a high rate of satisfaction. Two hundred streets have been improved or redeveloped through this function in addition to repairs and resolution of other issues. Detailed citizen profiles allows for geo-targeted polling, particularly around themes relating to renovation, where two thirds of citizens need to agree to demolition of a particular apartment block, according to the programme. This however has no basis in Russian law, which requires full consent of occupants before an apartment block is selected for demolition (Charley and Leslie, 2017).

A perceived lack of ownership is evident in cases where if no occupants of a block vote, that building is assumed to be compliant with demolition. In both online research and in interviews, respondents referred to the platform as “Fiktivniy Grazhdanin” (or fictitious citizen) owing to the lack of transparency around where ideas come from, the design of survey questions and the breakdown of voting results. In many cases there is no limit to the amount of times an individual can cast a vote on a particular issue. In conversation with the development team, it appears that the majority of ideas on AG come from within the local government system itself, while there is a separate ideas platform open for citizens with ideas for the city, What Moscow Wants (Moscow Mayor’s Office, 2018a). Interviewees referred to a case where voting on one issue (the renaming of a metro station) recorded ten votes every ten minutes consistently through the night which may suggest an automated programme was used to cast votes. In the context of voting around renovation or demolition (and displacement) however, further information is required to identify voters. Yet the perception that there is no real ownership over decision making on renovation in Moscow was common, with many seeing AG as a way to provide a veneer of compliance.

Governance
Moscow’s Smart City team (a function of the Mayor’s office) admits that local governance functions in a very top-down way. This team, however, emerged from a need to centralise information and communications technology systems so as to reduce duplication, incoherent procurement and public spending, deliver greater efficiency and reduce bureaucracy. This allows for a holistic view for planning for both public services and infrastructure. Ideas often come from the market, while specific government departments act as gatekeepers for ideas, that are then submitted to the team. Good ideas then undergo a proof of concept phase, before being presented to the mayor, and subsequently included on the AG platform, or not. During development of a large urban park (Zaryade), on a vacant site adjacent the Kremlin, citizens were polled on design concepts and spatial functions. In interviews however, respondents complained that it felt like AG was being used to facilitate already decided
procurement decisions, for instance around the removal and planting of trees in the city, or pavement installation. Many felt that while not overtly facilitating corruption, that AG represented a smokescreen of perceived openness around decision-making that was in fact only simulated.

With regard to renovation in particular, the ambiguity in Russian law around public ownership of property, owing to the change in economic systems presents unique difficulties. Effectively, private ownership of property in the case of mass housing extends only to the space of an apartment, meaning that the building fabric, envelope and environs remain effectively in state ownership (Semiletova, 2011). This allows for a situation where government, banks and development agencies keep a tight control over urban development and planning decisions. While a process does exist where citizens can achieve ownership of the (public) space which their building occupies, this involves a costly process where all apartment owners must agree to purchase the land together, employ a consultant who prepares a plan that must be accepted by the city authorities and included in the general plan for the city of Moscow (UNECE, 2004). This option is open to a truly limited number of citizens or communities (primarily due to the costs involved). In terms of the ability of citizens to influence wider urban development decisions effecting their local neighbourhood and the city of Moscow more generally, respondents felt that questions were designed in such a way as to encourage participants to select answers that would positively resonate with existing plans of the local government. A decision to establish an open-air museum at a site on Khokhlovskaya Square (Moscow Mayor’s Office, 2018b) was cited as an example of this.

Participation
Additional systems provided by the Moscow local government to allow citizens to suggest proposals or ideas for the city are not effectively connected into AG. Respondents complained that invariably the type of ideas to be voted on the AG platform were of little consequence to the actual urban development in the city, and participation was often open to decisions that had very little impact. Examples cited included decisions around the colour of seats in the Luzhniki stadium refurbishment, or the choice of tiles in an improvement of the urban realm. Respondents were highly sceptical that alongside an option of “Yes” or “No”, an option to “leave it to the experts” was also included, which was often the highest voted outcome in the case of important public realm decisions. This left citizens to feel that real participation in decision making was not possible around these issues. Citizens can earn points for participation in decision-making via AG platform (Moscow Mayor’s Office, 2017) – which can be exchanged for Metro credit and other prizes – incentivises participation, in particular those from lower economic backgrounds, increasing the potential for manipulation.

While the AG platform allows for geo-targeted polling of citizens around renovation or demolition, this is seen as designed to simulate a perceived participation, where truly open and transparent decision-making was lacking. The wider socio-economic context in Moscow, which remains the centre of economic activity in Russia, is an important consideration when looking at the context of public participation. Respondents noted the importance of the
construction industry in a difficult economic context of sanctions, as a factor in the urban development processes. This is perhaps evident in cases where buildings in good condition, occupying high value land are chosen for demolition, and others in a far worse condition in undesirable parts of the city are ignored. While there are clear advantages to urban development in engaging through online systems such as AG, these should not replace traditional forms of face-to-face engagement. This can be particularly difficult in a Russia, where policy exists to prohibit certain forms of public organisation or protest. More research needs to be done comparing hard data with decision-making outcomes to truly assess the value – transparency and openness - of the Aktivniy Grazhdanin platform.

Conclusions

One of the most novel aspects of the research approach is the international perspective, of particular importance as the intractable challenges that face communities are increasingly multifaceted and global in nature. The doctoral study comprises a number of case studies, selected for their socially innovative qualities, and investigated along a common pathway of deeply ethnographic action research. Relationships built up through dialogue with communities on the ground in Moscow, Christchurch and elsewhere, will form the basis of subsequent research inquiries through surveys and other mechanisms, in order to make comparative studies across the cases. Taking discussions with citizen and local government stakeholders on Aktivniy Grazhdanin into account, alongside the literature review into Smart City technology-led engagement more widely, it is clear that major concerns exist around ownership, governance and participation. While technology provides cheap and effective ways to engage citizens around issues that have little material impact on their day to day lives and future resilience, when decision-making is required on large issues such as renovation or displacement, there is no substitute for offline face-to-face engagement in a real-world context. In Scotland, this ambition is emphasised in the Scottish Government’s commitments to public engagement through the planning acts and charrette programme. In the context of Moscow, which is considered to be a world leader in facilitating urban development and socio-economic resilience for citizens through its Smart City programme (facilitated through Aktivniy Grazhdanin), the use of technology to sanction neo-liberal planning and construction processes is of great concern. More research and deeper ethnographic studies are required to better understand the impact and outcomes for citizens under the process of renovations and demolition. In particular, this should concentrate on the risks to maintain community resilience (alongside the ethics around acquiring private assets by displacement), and where truly socially innovative tools or actions could support citizens.

References


A Systematic Mapping Analysis to Guide Research on Comprehensive Life Cycle Assessment at Neighbourhood Scale

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Abstract: Urban settlements are not only bulk resource consumers, but also responsible for impressive loads to the immediate and global environments. As pollution, resource scarcity, climate change and extreme poverty are expected to worsen, sustainable urban planning approaches that regulate a balanced view of future developments must be increasingly consolidated. ‘Lifecycle thinking’ offers powerful and comprehensive conceptual approaches and methodologies to include sustainability solutions into city design, but applying such paradigm into urban contexts needs proper tools for accounting and defining sustainability measures and thresholds. Neighbourhoods represent both the minimum scale to consider urban spaces socio-economic dimensions and the typical operational scale for urban development projects. Assessments at this scale, therefore, offer an important complexity compromise. However, there is no consensual scientific approach for carrying out comprehensive life cycle assessments (LCA) at the neighbourhood scale. This paper aims at making a bibliometric analysis of existing literature and explores consistencies, limitations, challenges and research gaps on the topic to shed some light for future research. A systematic mapping analysis was performed in 1216 papers collected from all years and main databases, and relevant information was extracted and analysed from the 91 final sampled papers. Results show a publication spike from 2012, confirming the renewed interest in the subject and the scale; the main research groups, countries and journals investing in the theme and their different approaches; main challenges for applying LCA at neighbourhood scale; and the main research gaps, such as: the need for methodological choices standardization; the need for broader studies (comprehending more built environment components); the need for consequential studies; the lack of data and uncertainty analysis; among others.

Keywords: Comprehensive Life Cycle Assessment, Life Cycle thinking, Neighbourhood Scale, District Scale, Urban Metabolism.

Introduction

Inclusion of sustainability solutions into city design requires a rather different model from traditional urban planning and city management. Urban metabolism (UM) is considered fundamental to sustainable city development (Kennedy et al, 2011), and Lifecycle thinking and Industrial Ecology can offer powerful and comprehensive conceptual approaches and methodologies to do so. Nevertheless, for being an emerging field, applying LCA paradigm into urban contexts and development scenarios needs proper tools for accounting and defining sustainability measures and thresholds.

Beyond that, neighbourhoods constitute fundamental building blocks of a city and are complex, multifunctional, long-lasting dynamic systems. Therefore, understanding sustainability interactions at neighbourhood scale became so crucial for they represent both the minimum scale to take into account the socio-economic dimensions of an urban space and the typical operational scale for urban development projects, which necessarily include connections and dependency to the city’s systems of services and infrastructure (Lotteau et al, 2015a; Ayyoob, 2013; Berardi, 2011).

For having been developed to perform assessments at the product scale, within the built environment field, LCA has been mainly applied for construction materials and components (Bras et al, 2015; Saade et al, 2015). The increased number of attempts to
extend its use to whole buildings (Saade et al., 2014; Gomes da Silva and Silva, 2015) has motivated continuous investigations by task groups such as the Annex 57, on LCA-based embodied energy and global warming potential, and the recently launched Annex 72 on LCA of buildings. Studies at the city scale are, however, far more scarce, being most of them process-based LCAs focused on energy-related issues carried out in developed countries (Cabeza et al., 2014; Anderson et al., 2015a). Urban LCA has also been encouraged by UM field (Pincetl et al., 2012; 2014; Chester et al., 2012; Clark and Chester, 2017) and UM-LCA coupling has been suggested as a necessary UM third generation (Goldstein, 2013).

Furthermore, the growing interest on sustainability assessment at the neighbourhood scale may suggest that current building-focused environmental and energy concerns would soon be shifted to that scale (Oliver-Solà et al., 2011), taking the LCA approach with it, and demonstrating the need for studies in that area. Thus, this paper aims at making a bibliometric analysis of existing literature and explores consistencies, limitations, challenges and research gaps in this topic to shed some light for future research. For that, a systematic mapping analysis methodology was carried out so to extract and synthesize relevant information on the topic, aiming at answering the following research question: ‘What is the current state of arte research on LCA at the neighbourhood scale?’.

Method

Following the systematic literature review guidelines suggested by Kitchenham (2007) and the systematic mapping process developed by Petersen et al. (2008), later adapted by Paternoster et al. (2014), this research was developed in nine main steps:

i. **Definition of main research questions**: The research questions driving the research were outlined.

ii. **Search conduction**: Search terms, databases and search strings were defined.

iii. **Screening of relevant papers**: Exclusion criteria for screened sample were established.

iv. **Snowball Sampling**: An investigation of the hidden population of relevant papers was conducted through an exploratory reading of the final sampled papers, paying special attention to their bibliography, and other pertinent papers were added to the final sample.

v. **Keywording**: Aiming at creating a classification scheme between papers, a keywording process was accomplished. It basically consisted in skimming each of the final sampled paper and assigning a keyword that best described its contribution. These keywords were progressively combined and refined into a high-level set of categories that helped to comprehend the paper’s importance to the review.

vi. **Data extraction and mapping**: Key information were extracted from each paper and recorded in the shape of forms.

vii. **Rigor and relevance assessment**: Rigor is related to how an evaluation is performed and how it is reported, and relevance relates to the impact that the actors involved - study itself, researcher, publication source, etc. - cause through citations, impact factor, etc. (Ivarsson and Gorschek, 2011). Seeing as assessing rigor and relevance is a dangerous ground in regards to biases, in this step we simply aimed at ranking the primary sourced papers in terms of adhesion to the research topic.

viii. **Synthesis of findings**: Results were collected and summarized in descriptive (non-quantitative) or in statistical manner to obtain a quantitative synthesis.

ix. **Discussion**: The information extracted from most relevant papers was confronted and an analysis of main findings was made.
Results

Definition of main research questions

As stated in the introduction, the main research question driving this study was: ‘What is the current state of arte research on LCA at the neighbourhood scale?’ However, the following sub-questions were also made: (a) How to conduct a comprehensive LCA at the neighbourhood scale? (b) Which are the built environment components considered? (c) What are the challenges for applying LCA at neighbourhood scale? (d) Which are the current knowledge gaps? and (e) How are they dealing with the data requirements?

The first and second research sub-questions (a and b) intended to explore the methodological choices and system boundaries usually considered in neighbourhood LCA studies. The third sub-question (c) aimed at finding the difficulties inherent to LCA at the studied scale. The fourth sub-question (d) targeted determining future research possibilities. And the final sub-question (e) tried to understand if and how studies are dealing with the immense data requirement and uncertainty issues.

Search conduction

In sequence, two separate searches were conducted to find the primary papers to be analysed in the study, and both of them were guided throughout three phases (Melo et al, 2013). First, in regards to the Search Terms Definition phase, the following major search terms were defined from our research questions: ‘Life Cycle Assessment’, ‘Neighbourhood’ and ‘Urban Metabolism’ (this last one, to collect paper with more of an urban planning point of view).

Second, in concern to the Database Selection, three article databases were chosen for its coverage, peer-reviewed literature concentration and focus on the studied field: Scopus, Web of Science and Compendex. In addition, the proceedings of one specific key-conference was also used: Sustainable Built Environment regional conference Zurich 2016, entitled ‘Expanding Boundaries: Systems Thinking in the Built Environment’, because of its up-to-date, relevance and specific focus on the field.

Finally, on the Search String Formulation phase, considering synonyms, truncation symbol (*) and Boolean operators (AND, OR), the following search strings were used: (a) For Search #1, (‘life cycle a*’ AND (‘neighb*’ OR ‘district’)) appearing in title, abstract or keywords of researched papers; (b) For Search #2, (‘Urban Metabolism’ AND ‘life cycle*’ AND (‘neighb*’ OR ‘district’)) appearing in all fields. Additionally, as each database functions differently, we customized the search string, adapting the syntax to each of them.

Screening of Relevant Papers

The criterion that guided the inclusion of a paper on the final sample was that it should provide contribution or direct adhesion to the research questions. Essentially, we excluded search results that were: (a) Not peer-reviewed (any grey literature or books, apart from the conference purposely tackled); (b) Not written in English; (c) Unrelated to the field (e.g. papers on medicine, psychology, biology, chemistry, etc.) or to the urban scale; And (d) the ones that did not comprehend at least two of the five urban built environment components considered (material, energy, water, waste and mobility).

Search #1 resulted in 1041 papers, but after excluding directly at the databases all grey literature (E1), non-English (E2) and non-related to the field (E3) papers, a total of 707 continued in the screening process (322 from Scopus, 263 from Web of Science, 116 from Compendex, 6 and from SBEZurich2016). Search #2, on the other hand, resulted in 175
papers and subsequently, after the same first three exclusions, 123 papers were kept (111 from Scopus, 4 from Web of Science, 8 from Compendex and 0 from SBEZurich2016).

Subsequently, with the support of a research management tool, papers were merged into a single group and the following exclusion procedures were made: exclusion of duplicates (E4), exclusion by title (E5), exclusion by abstracts (E6) and exclusion by skimming (E7). Finally, the remaining amount after the screening process was of 64 adherent papers, equivalent to 5% of the total, and for the purpose of the systematic analysis, a track was kept regarding the reason for each exclusion done before and during the screening process, as seen in Table 1.

Table 1. Excluded papers rationale synthesis. Source: The authors

<table>
<thead>
<tr>
<th>Rationale</th>
<th>Search Papers #1</th>
<th>Search Papers #2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Excluded</td>
<td>Kept</td>
</tr>
<tr>
<td>Initial amount</td>
<td>-</td>
<td>1041</td>
</tr>
<tr>
<td>E1 Exclusion of grey literature</td>
<td>197</td>
<td>844</td>
</tr>
<tr>
<td>E2 Exclusion of non-English</td>
<td>44</td>
<td>800</td>
</tr>
<tr>
<td>E3 Exclusion of non-related to research field</td>
<td>93</td>
<td>707</td>
</tr>
<tr>
<td>E4 Exclusion of duplicates</td>
<td>301</td>
<td>406</td>
</tr>
<tr>
<td>E5 Exclusion by title</td>
<td>171</td>
<td>235</td>
</tr>
<tr>
<td>E6 Exclusion by abstract</td>
<td>187</td>
<td>48</td>
</tr>
<tr>
<td>E7 Exclusion by skimming</td>
<td>11</td>
<td>37</td>
</tr>
<tr>
<td>Total SLR excluded/kept papers</td>
<td>1152</td>
<td>64</td>
</tr>
</tbody>
</table>

Snowball Sampling

The exploratory reading of the final sampled papers allowed us to realize that mature researches specifically focused on neighbourhood LCA are scarce and a great percentage of studies in the topic are only available in grey literature, fact confirmed by Mirabella et al (2018a), who assumed they must still be under development. In consequence, the snowball sampling compiled to a larger number of papers than expected, summing up to 27 total (21 from scientific journals and 6 from conference proceedings). Furthermore, the English-only rule was also disregarded in this step, since within these papers, 2 important ones were in French. Finally, the final sample was composed by the 91 lasting papers as seen in Table 2.

Table 2. Final screened paper sample composition. Source: The authors

<table>
<thead>
<tr>
<th>Screening Step</th>
<th>Papers</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLR Total SLR kept papers</td>
<td>64</td>
<td>70%</td>
</tr>
<tr>
<td>SB Snowball sampling additions</td>
<td>27</td>
<td>30%</td>
</tr>
<tr>
<td>Final screened sample</td>
<td>91 Papers</td>
<td></td>
</tr>
</tbody>
</table>

Keywording

Two levels of keywords were established to each of the 91 selected papers. The first level regarded a specific keyword that best described the paper in its singularity and a total of 74 different keywords were awarded, being the most assigned one ‘Neighbourhood LCA’ for 10 papers. The second level consisted in the aggregation of similar keywords in one of the 16 higher-level categories illustrated in Figure 1. Results show that 27% of the screened papers
were mainly focused in ‘Neighbourhood LCA’, 10% in ‘Urban Sustainable Systems’, 9% in ‘Neighbourhood Hybrid LCA’, 9% in other ‘Neighbourhood Assessment Method’ and 7% in ‘Neighbourhood UM’.

Figure 1. Main second level keywords. Source: The authors.

Data extraction and mapping

Information was then extracted from the 91 selected papers, systematized in a spreadsheet and analysed in 14 categories: (i) Year of publication; (ii) Publication source; (iii) Research country; (iv) Research Institution; (v) Co-authorship network; (vi) Study field; (vii) Main study scale; (viii) Urban systems considered; (ix) Keyword level 1; (x) Keyword level 2; (xi) Relevance classification; (xii) Objective; (xiii) Main findings; (xiv) Research Gap.

Rigor and relevance assessment

Selected papers were ranked in 8 classes (A+, A, A-, B+, B, B-, C+, C) based on its adhesion to: having a comprehensive and detailed neighbourhood LCA framework outlined; answering the research questions asked; or to having important theoretical foundation to help find those answers. Figure 2 illustrate the number of papers ranked in each class (from highest adhesion A+ to lowest C) and results show that 28% of the papers were ranked as A; B+ (18%); B (17%); A+ (15%); A- (15%); B- (4%); C (2%); and C+ (1%).

Figure 2. Main second level keywords. Source: The authors.

Synthesis of findings

The first works concerning LCA at the neighbourhood scale date back to the beginning of 2000s (Fujita et al, 2000; Ge et al, 2003; Popovici and Peuportier, 2004; Forsberg et al, 2004), but publication numbers spiked from 2012 onwards (Figure 3), confirming the renewed and increased interest in the subject and the scale studied.
Results show that main scales addressed in the papers were ‘neighbourhood scale’ (54%); followed by ‘city scale’ (25%); then by studies with generic ‘urban scale’ (6%); and ‘territory scale’ (4%). Also, 9% of studies assessed varied scales and 2% of the papers, although linking to urban environment, were mainly focused in building scale. Furthermore, final papers can be divided in 3 major study fields: urban planning (53%), sustainable built environment engineering (34%) and environmental sustainability (13%).

In regards to publication source, 12% of the final sampled papers were published in the ‘Building and Environment’ journal (Impact Factor of 4.053); 10% in the ‘Journal of Cleaner Production’ (IF 5.715); 9% in the Journal of Industrial Ecology (IF 4.123); 8% in Zurich SBE2016 conference; 6% in ‘The International Journal of Life Cycle Assessment’ (IF 3.173); 4% in the ‘Renewable and Sustainable Energy Reviews’ (IF 8,050); and 7% in other conferences. Moreover, 12% of the papers were published in journals with double publications and 32% in journals with single publication.

In terms of geographical coverage, France (18%) and United States (18%) are the most productive countries in the field, followed by Canada (11%) and China (11%). Results also show (Figure 4) that developed countries (88%) are far more invested in researching neighbourhood LCA and urban metabolism, especially European countries (65%), and the only developing countries (12%) representatives were China (11%) and Mexico (1%).

Within the final sample, results express an occurrence of research group clusters (Figure 5) and that co-authorship among them only happen within their own country or with neighbouring countries. The largest cluster is formed by French researchers from Mines ParisTech (CES) and University Paris-East (CSTB), and Luxembourgian researchers from Luxembourg Institute of Science and Technology (LIST). Their researches are focused in: neighbourhood scale LCA (methodology and tools); integrated district systemic simulation toolchains; and building stock LCA using geographic information system (GIS). Within this cluster is the most productive author (out of the 278 total authors included in the sample), French Prof. Peuportier from Mines ParisTech who is responsible for authoring 7 papers total, all focused in neighbourhood LCA from a systemic point of view (Colombert et al, 2011; Peuportier and Roux, 2013; Roux et al, 2016). It is worth mentioning that Prof. Peuportier is from the ‘first generation’ of researchers to tackle comprehensive neighbourhood LCA (Popovici and Peuportier, 2004; Peuportier et al, 2006) and has been publishing in this topic mainly in conferences, being that 6 of his papers came from grey literature. Other featured
authors within this first cluster are researchers Herfray (5 papers) from Mines ParisTech (Herfray and Peuportier, 2010); Researchers Mailhac (4) and Schiopu (4) from University Paris-East (Mailhac et al, 2016; Schiopu et al, 2014; Sibiude et al, 2016; Beloin-Saint-Pierre, 2017); And researchers Benetto (4) and Popovici (4) from LIST (Mastrucci et al, 2016; 2017a; 2017b).

The second most important cluster is composed by Canadian researchers from University of Toronto and American researchers from University of California, Arizona State University and Humphrey School of Public Affairs. This cluster’s researches are considered very important due to the fact that they come from an UM background, a field that has been researching urban system’s complexity and its interaction with the environment for over 50 years, and to not consider/understand its evolution process along these year could mean repeating seminal mistakes and a great setback for sustainable urban development. Within this group is Canadian Prof. Kennedy from University of Victoria (previously in University of Toronto) who is responsible for 6 of the papers, focused in: urban metabolism (Kennedy et al, 2007 and 2011); neighbourhood metabolism (Codoban and Kennedy, 2008); neighbourhood economic input–output life cycle assessment (EIO-LCA) (Norman et al, 2006); sustainable urban systems (Kenney et al, 2012) and infrastructure interactions (Engel-Yan et al, 2005). This cluster also features Prof. Pincetl (4 papers) from University of California and Prof. Chester (4 papers) from Arizona State University, both leading researchers advocating for the integration of LCA in UM studies (Pincetl et al, 2012; 2014; Chester et al, 2012; 2013; Clark and Chester, 2017).

Subsequently, the third most relevant cluster is formed by two research groups – one Belgium from KU Leuven and other French from Agro ParisTech – that bundle together due to a common researcher. Within this group is the third most productive author of the bunch, Belgium Prof. Allacker from KU Leuven, who is responsible for 5 papers focused in neighbourhood and road infrastructure LCA (Trigaux et al, 2014, 2016 and 2017) and city scale LCA (Mirabella et al, 2018a and 2018b). Other important author highlighted in this cluster is Dr. Loiseau, a leading researcher on territorial LCA (Loiseau et al, 2013; 2014; 2018) responsible for 3 of the sampled papers. In sequence, another cluster occur between French and Spanish research centres, Nobatek and Tecnalia, who are responsible for the most focused review on neighbourhood LCA (Lotteau et al, 2015a) and the development and application of the Neighbourhood Evaluation for Sustainable Territories (NEST) LCA tool (Lotteau et al, 2015b; Oregi, 2061).

Lastly, but not least, smaller clusters occur within their own institution or country, nonetheless resulting in important studies, such as: Neighbourhood and building stock hybrid IO-LCA (Stephan et al, 2013; Stephan and Athanassiadis, 2016), an urban environmental sustainability assessment general techniques review divided in 3 categories (consumption-based, metabolism-based and complex systems approaches) (Baynes and Wiedmann, 2012), and an integrated neighbourhood LCA-carbon footprint hybrid model (Huang et al, 2017) by Australian research groups; An expanded analysis framework to account for the interplay between the building and city level (Anderson, 2015a) and LCA to determine induced impacts in Munich urban region (Anderson, 2015b) by German research group; A review of life cycle thinking studies towards sustainable cities devised in an 8 urban issues - buildings, energy, food, green spaces and landscape increase, mobility, urban planning, waste and water (Petit-Boix, 2017), an urban characterization model based on hybrid LCA-GIS bottom-up methodologies (García-Pérez, 2018) and a sustainability indices, standards and guidelines review analysing its suitability to life cycle thinking (Albertí et al,
2017) by Spanish research groups; The development of five different city patterns to reflect on accessibility and resident/employment density profile (Nichols and Kockelman, 2015) based on neighbourhood LCA studies in Austin (Nichols and Kockelman, 2014), the development of a LCA-CAD tool to estimate urban design embodied energy (Davila and Reinhart, 2013) and a Kuwaiti neighbourhood LCA study using Urban Modeling Interface (UMI) (De Wolf et al, 2017) by American research groups.

Discussion

Comparison of the sampled researches shows that urban scale LCA studies are mainly sought out as a policy making supporting tool or for strategic scenario comparison; up to this date comprehensive LCA has not been applied to the entire urban scale; and upscaling approaches are urgently pursued and still in development (Mirabella et al, 2018a). Additionally, it confirmed a lack of consensus and standardized procedures when regarding comprehensive neighbourhood LCA due to the fact that studies differ greatly in each critical methodological aspect, from goal and scope definition, system boundaries, life span and life cycle steps considered in foreground and background data collection, inventory indicators,
impact and damage categories, allocation criteria, normalization, weighting, among others. (Lotteau et al., 2015; De Wolf et al, 2017; Huang et al, 2017). The functional unit, for example, is usually unclear, highly heterogeneous, referring to the neighbourhood, spatial functional unit, household or individuals (Lotteau et al, 2015), and a few authors have considered that this might be a reflection of the lack of consensus also on a proper definition of what a city/neighbourhood is and what its functions are (Albertí et al, 2017). For that matter, in terms of system boundaries, neighbourhood sizes varied immensely, and few papers conducted a more comprehensive LCA and analysed at least four different fields of the built environment - buildings, open spaces, networks and mobility (Norman et al, 2006; Stephan et al, 2013; Nichols and Kockelman, 2014; Mailhac et al, 2016). However, even amongst these, a comparison was not straightforward as each of the four fields, the physical elements and associated contributors considered (type of roads, parking, green space, electricity, water, gas, waste management, different transport modes, among many others) varied, as well as the decision to either neglect or take them into account.

**Challenges for applying LCA at neighbourhood scale**

As we zoom out from material to urban scale, the complexity of studied systems bring in new challenges that are superimposed to the intrinsic limitations of the LCA technique. The main overall challenges for quantitative environmental modelling refer to defining the system’s functions (i.e. basis of comparison between development scenarios) and finding enough representative data to model its network and its effects on the environment. The number of data sources to consider adds complexity to the modelled system, and the magnitude of relative uncertainty (e.g. over 5% of the median value) impairs reliability (Beloin-Saint-Pierre et al, 2016). In LCA, the functional unit is the basis for describing the function of a system and comparing environmental impacts for different alternatives of scenarios. When the analysed systems provide a combination of functions, the comparison is only valid if both systems are functionally equivalent, i.e.: perform the same mix of functions. UMs offer a multitude of functions that might not be easy to divide.

UM effects on the environment might vary significantly over time due to changes in consumption patterns, underlying economic activities and technologies. Time-series modelling based on projections from annual statistical datasets offer information on the number of environmental effects but do not track the functions they are linked to (i.e. activities and processes that cause them). Assessment of UMs sustainability (e.g. urban consumption) trends, therefore, requires interpretation from environmental specialists. Contrastingly, a life cycle-based UM model is more complex to implement but offers results that are simpler for decision-makers to analyse, and facilitate urban planning options screening from an environmental viewpoint. Time-series LCAs allow monitoring of temporal evolution of an UM's impacts to fundament sustainability analysis over time and to identify if a given scenario is sustainable in the future. Such modelling approach is not currently standard (Beloin-Saint-Pierre et al, 2016), but seems to have attracted research in the past four years or so. Also, consequential LCAs are particularly suitable for hypothetical multi-scenario evaluation.

Addressing spatialization of impacts is also a challenge and choosing appropriate models and LCIA method to identify global, regional and local impacts is essential for a more effective and conscious decision-making process (Mirabella et al, 2018b). Additionally, there is a difficulty for considering transboundary processes in the assessment, including both upstream and downstream flows (Mirabella et al, 2018a).
Knowledge gaps and research recommendations

Our systematic mapping showed that the most common implementation issue raised by urban scale quantitative environmental assessment studies is the lack of data to describe the numerous parts of urban flows and systems, with recurring suggestions for further research concerning sensitivity analysis and data uncertainty. Scope broadening to include social and economic issues, standardized procedures and the normalization step along LCA were also identified gaps.

Furthermore, Lotteau et al (2015) pointed out a comprehensive list of recommendations and research efforts to allow sound LCA application at urban settlements and neighbourhoods scale. Chester et al (2012) called on urban sustainability practitioners to contemplate new methods for integrating intangible forces in UM-LCA studies so to comprehend the anthropogenic drivers that shape the technical, cultural, institutional, economic and psychological fabric of cities. Goldstein et al (2013) drew attention to the issue of integrating UM–LCA results into the SUD policy implementation. Finally, Beloin-Saint-Pierre et al. (2016) explored methodological and implementation options from the field of industrial ecology and more specifically for the assessment of regions (Loiseau et al., 2013; Lotteau et al., 2015a) to suggest pathways to improve results comparability.

Data requirements and uncertainty

LCA, with its comprehensive and detailed scope, is probably the most data intensive method in industrial ecology (Beloin-Saint-Pierre et al, 2016). This fact shapes two opposite faces of the same coin: while allowing for detailed, multi-criterial assessments, data requirements are massive and are further intensified by neighbourhood assessment idiosyncrasies. The balance point between required vs. feasible information collection varies across UM’s components, as varies the maturity of available tools, methods and models (inventory and pathways) and simulation algorithms. Such variation defines detailing level and result resolution and should be indicated accordingly.

According to the modelling approaches characterized by Beloin-Saint-Pierre et al (2016), selections of data treatment depends greatly on the nature of expected results. If focus is shed on substance flows within the system, a highly-aggregated black box approach might suffice, while network analysis is more appropriate to understand exchange between ‘nodes’ of processes/components. Truth is that the more detailed and broken-down the desired results are, the more time consuming the analysis will be and larger the amount of required data and the inherent difficulties to get them. Whilst network modelling was suggested by those authors as ideal, for enabling understanding of the relations among the UM components, an intermediate grey box modelling would provide some component disaggregation and allow for more flexible top-down/bottom-up data input at less stringent data requirements. Links between sectors would not be characterized and therefore prevent hot spot identification, but this could be a feasible compromise to explore in severe data restriction contexts. Therefore, in terms of data handling, neighbourhood seems to be a good meso-scale to tackle urban LCA issue because the larger the scale (i.e. city, urban region, territory), the more aggregated data will be and more uncertainty it will provide (Mirabella et al, 2018a), and, contrastingly, the smallest the scale (i.e. building) more financially and time-consuming it will be. Neighbourhood analysis can work as a cell of the urban matrix and generate more precise environmental impacts assessments collecting easier bottom-up e top-down data.
The term ‘uncertainty’ represents all variability and uncertainty of information present in LCA since ISO14040/1997. Three types of uncertainty can be distinguished: 1) Parameters uncertainty, related to the difficulty to accurately define observed or measured values in a model; 2) Scenario uncertainty, related to the characteristics and normative choices made in response to geographical location of the system boundary; and 3) Model uncertainty, related to possible variability in structure and mathematical relationships within models. These uncertainties can come from different sources, such as: random error and statistical variation, systematic error and subjective judgment, variability, inherent randomness and unpredictability, expert uncertainty and disagreement, linguistic imprecision and approximation (Lloyd and Ries, 2007).

Indeed, it has been vastly argued that the main limitations regarding LCA and UM are related to the data collection process and its analysis. Shahrokni et al (2015) enumerated these limitations in four main categories: 1) lack of data at the urban scale; 2) high data and resource requirements; 3) need for follow up studies to analyse flows evolution; and 4) difficulty to identify cause and effect relationships, especially considering the ‘little attention paid to socioeconomic and political driving forces and the function of an urban system and its environmental performance. Lastly, as to uncertainty results, use of Monte Carlo-based simulation to obtain a distribution of uncertainty to describe results, and of fuzzy numbers seem to be promising (Beloin-Saint-Pierre et al, 2016).

Conclusion

Analysis of the final sampled papers evidenced methodological heterogeneity and that a comprehensive approach for carrying out LCA at the neighbourhood scale has not reached consensus within the scientific community. An integrated systemic simulation can help in that direction, but only if harmonization of simulation hypothesis (e.g. foreground data, such as building occupation rate; and background data, such as weather data) and methodological choices (such as simulation scale - local, regional or global; components included; LCIA method; environmental impact allocation method) can be achieved.

By means of a systematic mapping analysis, we provided a systematization of the state-of-art, assessed relevance of the identified primary studies, and analysed limitations, and challenges within the scope of neighbourhoods LCA. Our research also enabled the identification of main research gaps in the studied field, such as: the need for standardization of methodological choices; the need for broader studies (comprehending more components of the built environment); the need of integration between urban systems; the lack of data; and sensitivity and uncertainty analysis.

Finally, as mainly being adapted and up/downscaled from two distinct scales (building and city) and fields (sustainable built environment engineering and urban metabolism), studies invested in solving neighbourhood LCA problematic keeps on being mostly focused on biophysical urban flows systemic relations, which maintains it blindsided to the intangible forces that shape the urban environment. Therefore, interdisciplinary studies comprehending cultural, institutional, psychological, social and economic anthropogenic urban shapers could truly support policy-making and sustainable urban development.

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Urban Social Sustainability in the Era of Digital Technology: the case of NEOM, the World’s Future Global Hub across Three Countries

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Abstract: In October 2017, the launch of the mega city of NEOM has been announced, covering 26,500 km² of land in Saudi Arabia, Egypt and Jordan: a strategic location along one of the world’s most prominent economic arteries (the Red Sea), making it a global hub for trade, innovation and knowledge. As per http://discoverneom.com, NEOM focuses on nine specialized investment sectors: energy and water, mobility, biotech, food, technological and digital sciences, advanced manufacturing, media, entertainment, and liveability.

We think that NEOM demonstrates a new way of urban development that is closely related to sustainability principles and to the era of digital technology. In fact, it is a phenomenon that deserves observation, research and analysis. However, in many cases, the debate on urban sustainability has mainly focused on environmental and economic factors, often neglecting essential social aspects. The main focus of this paper is to examine how urban social sustainability could be achieved in NEOM alongside new urban development practices in the era of digital technology.

The paper starts out by defining and delineating a framework of urban social sustainability, with its key dimensions. It then moves on to the analysis of NEOM’s planning principles and design concepts, tackling its nine sectors and examining their relationship with urban social sustainability and liveability. At the end, recommendations for creating and maintaining a rich social life within NEOM’s urban spaces are suggested, showing how new urban planning practices in the era of digital technology should enhance equity, community and urbanity.

Keywords: Urban Social Sustainability; NEOM; Social Inclusion/ Cohesion/ Resilience; Social Exclusion; Pre-Urban Gentrification

Introduction: A New Vision of Urban Development

Recently, the world is witnessing the emergence of various examples of "eco-cities" that are specially designed with an eco-environmental awareness, constructions with technological sophistication, propositions for renewable energy sources, dreams of social diversity/inclusion and self-sufficient resources. Following the same model, the construction of the new city of NEOM was announced in October 2017 in Riyadh, the Saudi Arabian capital. NEOM is a manifestation of investors’ dreams, a hope to create a city of the future like it has never been before (Zareva, 2017). NEOM will be built from a scratch like a science fiction city on virgin land between Saudi Arabia, Egypt and Jordan. This independent zone, that has its own social norms and regulations, will take the lead as a new way of urban development. NEOM is an initiative to explore new economic opportunities that emerged from Saudi Vision 2030, in the hope of reducing Saudi Arabia’s dependence on oil. This new zone will be created in order to attract the world’s top talents, as it will enhance the wellbeing of its citizens and serve their economic progress. The New City of NEOM is aimed to be the biggest hub of innovation, trade and creativity. Moreover, the proposed city will function independently from the existing Saudi governmental regime. It will have its own autonomous judicial systems as well as labour and taxing laws.
On the one hand, NEOM’s vision is about developing the land of the future, where the biggest talents and greatest minds unite together to prevail and surpass all limitations in a world inspired by imagination. On the other hand, its mission is about the creation of an exclusive location, uniquely qualified for private investment and participation under an effective governance system (Zareva, 2017).

Although the sustainability concept encompasses a social mandate, this aspect was almost neglected for more than two decades in urban sustainability research. Moreover, the definition of social sustainability in the built environment disciplines has witnessed little attention, despite the anthropocentric focus on the definition of sustainability (Hopwood et al., 2005). This is why, the idea of NEOM, as a new smart urban community that promotes urban and economic sustainability, led us to various questions concerning its social sustainability and the composition of its society: will NEOM receive different social categories worldwide? If yes, will all social criteria be able to coexist there? Will the new city be consciously conceived, based on social inclusion or will its development create another bubble of social exclusion, as it will be certainly pre-urbanely gentrified? (Mahmoud, 2017)

We believe that the composition of the society, its behaviour and its fusion, is very critical, as it will affect its economic and environmental development and thus, its urban/social sustainability. So NEOM’s new society structure, whether it is homogeneous or heterogeneous, is considered critical when addressing its urban sustainability.

This paper seeks to raise awareness on how to propose ideas to make NEOM socially sustainable and smart, to be able to ultimately achieve its general sustainability. It argues that social diversity can either create a hub of creativity and intelligence or a bubble of social exclusion that can ruin a new community. The first goal can be achieved via the creation of communal consciousness that can be realized through the participation of all citizens in the foundation of their community from the very beginning, with the support of economic and political capitals. This process will help create a potential foundation that can raise the communal urban consciousnesses. New societies should be able to create the sense of place and community among their inhabitants. Substantial progress, to increase social sustainability in new urban developments, requires widespread public, communal and governmental supports, and therefore depends on whether these communities are socially inclusive and cohesive or not. Otherwise, new communities like NEOM will only represent certain groups of inhabitants, based on their socio-economic status and potentials that is likely to alienate NEOM from its citizens via the creation of bubbles of social exclusion.

**Paper’s Interests and Objectives**

This research presents a general framework of analysis for urban/social sustainability in the era of digital technology, as well as for eco-city development with a special mention of the city of NEOM. It is a specific assessment of the benefits and disadvantages of the NEOM project, especially on the social level. Although NEOM may represent a new vision of an attractive, utopian, liveable urban community that integrates tangibly and firmly both eco-environmental and economic aspects of sustainability, it may perpetuate certain undesirable social effects. We believe that in order for NEOM to be socially sustainable, all citizens should be engaged from the very beginning in the weaving of the social tissue of this urban community. Moreover, this engagement will depend in a way on NEOM’s capability to offer clear benefits for its residents’ quality of life, and whether these benefits are sustainable and evolutionary or not.
Research Approach

This paper adopts an integrated analytical approach that is nourished differently. To be capable of exploring the urban and social sustainability in the era of digital technology, literature review that covers a wide spectrum of social/urban sustainability notions will support our research. Moreover, we will also go through new terms such as pre-urban gentrification to be able to apprehend a specific urban/social mechanism that might function and affect the urban/social evolution of new urban communities (Mahmoud, 2017). Furthermore, examples of other cities that have been conceived and function following the same urban notion will be scrutinized. These examples, in addition to data and graphic analysis, will constitute a set of guidelines serving to support our hypothesis and to comprehend NEOM's future social/urban mechanism.

Literature Review

NEOM urban/social sustainability in the digital modern era requires the understanding of various phenomena and terms of urban sociology and development. To be able to understand the social dimension of sustainability, we need to scrutinize concepts of social sustainability and its dimensions. Moreover, some key factors that affect the achievement of social sustainability need to be reviewed such as social inclusion/exclusion, social cohesion and pre-urban gentrification.

Sustainability, Social Sustainability and its Dimensions

In the "Dictionary.com" the word sustainability in general is "the ability to be sustained, supported, upheld, or confirmed". Although in the same dictionary, it is defined in environmental science as "the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance". According to the Brundtland Commission in 1987, the definition of sustainability is "meeting the needs of today without compromising the ability of future generations to meet their own needs."

On the one hand, one's economic status affects largely his/her social wellbeing and whether he/she makes enough money to support their lives with dignity. On the other hand, the social wellbeing is also affected by the environment as physical environment and its resources are employed to serve the human being and his needs. The social aspect of sustainability is naturally knotted with both the economic and the environmental aspects.

In fact we believe that the human sustainability is initially a social process: humans can't neither live nor thrive unless they interact with their environment, which consequently becomes the product of these human being as cultural, natural and built environment. So social sustainability is about people and how to meet their needs and requirements (Brain, 2017).

Social sustainability is a term used to describe the stability and durability of certain social groups and their practices in a certain urban space. Maintaining a kind of stability in social practices leads to a stable social production of urban space. For example, decisions and norms -such as technological change or economic activity- assigned by a group of people to socially practice in a certain space, affect the allowed opportunities for future generations and thus their social sustainability. So basically, we should consider the consequences of our actions, decisions and urban politics on the wider community. Moreover, we should anticipate and embrace social changes to enhance people's future wellbeing. The concept of social sustainability is a complex multi-dimensional process, relying on a fundamental question "what are the social goals of sustainable development?"
Social sustainability takes into consideration the ability of individuals and communities to live with each other, to flourish and to meet the societal expectations and provisions for community connectedness, safety, equity, freedom, citizenship, individual autonomy, propagation of knowledge, resources distribution, participation in governance and rule making, etc.

There are non-physical and predominant physical factors we should consider in order to achieve urban and social sustainability. Some of the most important non-physical factors are social inclusion and eradication of social exclusion, social cohesion and social interaction. We believe that social cohesion in an urban community is a necessity to be able to achieve and maintain common goals, as well as individual needs of well-being, health, shelter and education, etc.

**Social Inclusion/Exclusion, Social Cohesion**

We use the term of "social exclusion or marginalization" when a certain social group or individuals are excluded or pushed away from the society. This societal exclusion might take the form of being deprived from accessing some services or practicing certain rights that are available for other individuals. Social exclusion process is the opposite of social inclusion and prohibits the social cohesion progress. The absence of social cohesion leads to social polarization of the society as well as social-spatial segregation of undesired groups in relation to their social class, race, skin colour or economic status. While the social exclusion process can happen in a natural way, due to lack of money or social status -that is usually translated by their inability to profit from certain services or to access specific spaces-, it can also be artificially endorsed by embracing certain urban policies. Some actions like pre-urban gentrification, ghettoïsation, either rich or poor, reinforce the social exclusion and the socio-spatial segregation of the community. The latter affects negatively the social cohesion of a society and thus its social sustainability. Social cohesion and social exclusion are two phenomena underlined by Emile Durkheim as the key of societal resilience. They can either tie together the individuals of a certain community in multidimensional relationships, or tear apart the same community with weak social bonds (Durkheim, 1895). This is why social cohesion is a real key to achieving social sustainability, as each individual has a place, a space and a role in the community. Social cohesion depends largely on the ability of the society members to cooperate and on their willingness to achieve common goals to prosper and survive. Therefore, the power of each society is the outcome of blending all the potentials of its members. Social life is "made up of the mass of individuals, who constitute society, the manner in which they have settled upon the earth, the nature and configuration of those things of all kinds which affect collective relationships." (Durkheim, 1895:241).

**Pre-urban gentrification**

The term "gentrification" was originally used to point out a certain urban process that takes place mainly in pre-urbanized areas initially conceived for unprivileged social classes. This process is about the replacement of poor social groups by richer ones, which will have as a consequence, an increase of cultural and economic values of properties that were previously owned by the poor. This "negative" process, from at least the original owners' point of view, usually transforms several areas worldwide (Madden, 2103).

Yet, the term is believed to be more simultaneously complex and paradoxical as it incorporates a lot more than a process of urban displacement and metamorphoses. In fact,
this process is not limited to previously urbanised decaying areas, since new settlements can be pre-urbanely gentrified during its conception (Mahmoud, 2017).

The pre-urban gentrification of a new settlement or a new city takes place during the decision-making stage of its creation due to various reasons such as urban policies, economic or cultural pressures, etc. The complex process of pre-urban gentrification is set-off by introducing gentrification nodes in the "un-urbanized" urban tissue. The gentrification nodes are mainly represented by high-end residential areas or units such as lavish villas and palaces, luxurious shopping spots, out-of-reach private educational institutions, etc. Once these nodes are embedded in the urban tissue of a future settlement, they connect like neurotransmitters progressively spreading their impact. The latter converts the urban tissue into an ideal flora for a gentrification process to thrive (Mahmoud, 2017). The in-between areas will either follow the same process or they will be abandoned by the population because they will be symbols of social alienation.

![Pre-urban Gentrification Process](image)

Figure 1: Pre-urban Gentrification Process. Source: (Mahmoud, 2017)

We believe that the process of pre-urban gentrification is quite alarming when it comes to the development of new cities or settlements; it puts the society into jeopardy especially, its social structure, sustainability and resilience. The consequences of such actions are that the unprivileged social groups will isolate themselves away from the whole community. They will either encapsulate in marginalized areas or create a parallel world, in which they can feel more blended and integrated. However, they might maintain a certain interaction with the other privileged society as working class. Accordingly, pre-urban gentrification plays a main role in polarizing societies, which puts the community at risk, as it will be more vulnerable, socially unsustainable and less resilient.

**NEOM: The world’s future global hub across three countries**

NEOM is planned to be the world’s first independent special zone, located in the north-western region of Saudi Arabia and is set to include territory from within the Egyptian and Jordanian borders, to comprise a total area of 26,500 km², along beautiful beaches and mountains.
The city was announced by Saudi Crown Prince Mohammad bin Salman at the Future Investment Initiative conference in Riyadh, Saudi Arabia on October 24th, 2017. NEOM emerged from Saudi Vision 2030 and will operate independently from the existing governmental framework with its own tax and labour laws and an autonomous judicial system. NEOM will not only become a test case for a zero-energy mega-city (with a size 33 times that of New York), but it will provide abundant opportunities for employment and investments within Saudi Arabia, attracting local and foreign money back to the country (Zareva, 2017). The vision is utopian, aiming at developing the land of the future, where the greatest minds and best talents are empowered to embody pioneering ideas and exceed boundaries, in a world inspired by imagination. However, the mission is to create a unique location for private participation and investment within an effective governance system (http://www.neom.com/).

NEOM focuses on nine specialised investment sectors: energy and water, biotech, food, technological and digital sciences, advanced manufacturing, media, entertainment, mobility and liveability. Concerning energy and water, NEOM will include vast fields of solar panels paired with wind turbines and large energy grids for power storage over the years, mainly aiming to supply all of NEOM and beyond, with low-cost regenerative energy. Regarding biotech, NEOM is expected to excel in next-generation gene therapy, genomics, stem cell research, nano-biology and bioengineering, aiming to achieve the world’s future wellbeing and fulfillment (http://www.neom.com/). NEOM will also find a way to assure food supply for its resident, by introducing and using seawater farming and solar-powered greenhouses, as well as vertical urban farms, delivering fresh products to its citizens with extraordinary speed and space efficiency. Technological and digital sciences are main focuses of NEOM, with open source platforms, inviting the world’s top data scientists to analyse data and bring along innovative ideas. NEOM will excel in advanced manufacturing, seeking innovations in nanotechnology, 3D printing, sensors, Internet of Things (IoT) devices, electrical vehicles, robotics and renewables. Also, NEOM will support and create innovative
ideas and strategies in the field of media and entertainment to seize the world’s attention, becoming a media hub, not just for the Middle East, but the entire world (http://www.neom.com/). While creating a new generation city, one of the most essential focuses will be on mobility, thus, NEOM will provide its inhabitants with convenient accessibility, allowing them to reach their destinations by walking to encourage a healthier lifestyle. In addition, it is expected to engage automated, 100% green transport systems that will travel smoothly and safely in three dimensions, through air, land and sea; as well as assuring new outward connections: represented in a new bridge that will link Asia with Africa and be as strong as NEOM’s iconic design (Debusmann Jr, 2018). The last of NEOM’s nine sectors, and the most important one for this paper, is the liveability of the city. NEOM is expected to develop as a leading global hub that sponsors the change of the future of human civilization, by offering its inhabitants an ideal lifestyle. Also, NEOM will seek to attract top quality talents from around the world to push the boundaries of innovation. It aims at offering its inhabitants an idyllic lifestyle that surpasses that of any other metropolis by assuring the creation of a community, founded on modern architecture, lush green spaces, quality of life, safety, and technology to serve humanity. Public services will be fully-automated to help provide efficient services for its residents and businesses. NEOM will also provide its residents with free facilities, such as comprehensive free internet coverage, consequently, supporting education and communication.

Figure 4: The nine specialised investment sectors of NEOM. Source: http://www.neom.com/

It is claimed that NEOM will provide a unique societal experience that covers many aspects of social sustainability, while focusing on education-for-everyone, arts and culture, as well as creating a favourable business environment, and encouraging systems that attract investment and assure the highest quality of life for a comfortable and peaceful community.

NEOM shall attract inhabitants from all the world’s continents to ensure a multicultural environment that encourages a proactive and diverse community. Good quality transportation will be certified by the city to guarantee fast and efficient mobility across NEOM. Comfortable housing, safety and security are main focuses of NEOM, and healthcare is assured by world-class facilities, using advanced capabilities to provide an all-round service (http://www.neom.com/).

The futuristic vision of the project comprises six main pillars that will be adopted across NEOM:

Firstly, considering human beings as a top priority: NEOM provides its residents with comfortable living conditions within an ideal society that promotes inclusion and encourages personal growth respecting world-class social norms.

Then, ensuring healthy living and transport for the next generation: NEOM will allow its residents to reach many locations by walking or biking and also have an unprecedented
transportation infrastructure, built on future transportation technologies (Debusmann Jr, 2018).

Including large scales of automated services and electronic government strategies will be implemented, as NEOM government services will be fully-automated and easily accessible to its residents.

NEOM will also offer its residents innovations in the digital field as they will enjoy multiple advanced aspects of digitalization including “digital air”, free highest-speed internet and free online continuous education.

Sustainability is one of NEOM’s main focuses concerning futuristic concepts, the city will be powered by renewable energy and buildings will have a net zero carbon footprint.

The city will be considered as a laboratory for innovative construction techniques and materials operating with complete flexibility to meet future requirements.

While the scope of ambition for this urban project may be unprecedented for this century, its necessity is evident. With falling oil prices and declining demand, as well as insufficient investment opportunities at home, Saudi Arabia is searching for its place in the future (Zareva, 2017).

Utopia of the Modern Era: A Hub of Social Diversity vs. a Bubble of Social Exclusion

Urban and eco-environmental sustainability is twined with social sustainability. This is why we should consider social sustainability from the beginning. The quasi-absence of social aspect in studies and application of new urban development and communities weakens these developments and doubts their continuity. Every decision taken within urban policies of a certain community affects its social and economic sustainability. This is why, if we aim to attain a certain level of social sustainability, we, as planners, should shift from a reactive approach to proactive one (Brain, 2017). Investing more time and effort in the social studies for the new urban communities, being convinced that social sustainability is the real key for urban and eco-environmental sustainability, will allow us to move away from treatment action to preventive approach. Determining the social needs of a new urban community before its urbanisation -based on the targeted social group that will occupy this new settlement- will enable us to tackle the determinants of social issues rather than the aftermath problems themselves. Social sustainability is achieved when all the organisms of one community support the capacity of current and future generations in order to create healthy and liveable communities (McKenzie, 2004). More explicitly, it occurs when both the informal and formal systems, process, structures and relationships in the same society, create a dialogue together to achieve common goals and wellbeing for the inhabitants of this community regardless of their social classes or economic status. When social sustainable communities are achieved, they become more resilient as they provide connected, democratic, equitable, diverse quality of life. Consequently, each individual feels the responsibility and takes every possible action to sustain the quality of life he/she acquired. Being an active member of the community is the real key for its social sustainability.

New communities created from scratch, focusing on specialised investments such as NEOM, Astana in Kazakhstan and Konza in Kenya, are even more fragile. The urban development of these new communities are usually announced to be based on social diversity, however their capabilities of maintaining this diversity rarely exist.
In case of Astana, the capital city of Kazakhstan, social sustainability has not been addressed. The city is located on the banks of the Ishim River in the north portion of Kazakhstan, with an area of 810.2 km$^2$ and a population of 1,029,556 people. Despite the fact that the main goal in the development of the city of Astana has been to reach universal access to safe, inclusive and accessible public spaces, in particular for women and children, older persons, and persons with disabilities; by 2030; according to the UN-HABITAT, there is a lack of social inclusion and sustainability, represented in neglecting the human scale, which makes the city become “ugly”. Also, the lack of good public urban spaces, such as open spaces, parks, and public buildings, is the main reason for reaching low liveability levels in the city.

In order to find solutions for the problem, the city of Astana participated in an international workshop called “Vitalizing Cities with Public Space”, that was held in Seoul on November 14-17, 2016, to discuss challenges and opportunities for better urban planning and design, in order to achieve the expected goals in the field of urban social sustainability (CURB, 2015) and (Khan, 2011).

On the other hand, Konza in Kenya, the Techno City project was planned differently in 2009. The city was initiated with the procurement of a 5,000-acre parcel of land at Malili Ranch, 60km south east of Nairobi along Mombasa-Nairobi Highway in Kenya. It was conceived to capture the growing global business, processing, outsourcing and information-technology-enabled-services sectors in Kenya. While designing the master plan, the idea of sustainability was mainly considered in the land use, in order to avoid the lack of socio-cultural sustainability.

Konza was planned as a mixed-use, high-density walkable city in order to accommodate a diversity of programs and districts. Konza is expected to be a liveable urban environment that encourages high-value development and discourages sprawl; and this was achieved by avoiding superblocks and auto-orientated roadways. Planning was intended to take inspirations from successful global urban centers, and to satisfy the needs of Kenya and the region. The master plan aims to let the city function globally and locally, throughout the
years. These concepts of liveability, density, and walkability were incorporated in the Local Physical Development Plan of the city (Johari, 2015).

Also, concerning the city data, Konza’s inhabitants are meant to have direct access to all the data, including traffic maps, emergency warnings, and detailed information describing water and energy consumption. The availability of data is intended to let Konza’s inhabitants interact and contribute directly to the operations of the city, practice more sustainable living patterns, and enhance overall inclusiveness. Achieving the smart city framework will let Konza be able to optimize its city services and to create a sustainable city that responds directly to the needs of its residents, workers, and visitors (Johari, 2015).

In case of NEOM, where "foreigners" are invited to create the world biggest hub of creativity, innovation and imagination, it is mandatory to be well aware of the consequences of creating such a new community. NEOM will not only be a mega city, 33 times the size of New York, but also an experiment for zero-energy community that provide plentiful and ample opportunities for both Saudi and foreign investors (Zareva, 2017). Consciousness about social sustainability, its consequences and its needs in the planning of these new communities will enable them to thrive steadily and continuously. It will help to avoid various social problems such as social exclusion, deprivation and poverty, crime and safety issues, inequality, segregation of communities and low quality of life.

Concerning NEOM and whether it will be urbanely, economically and socially sustainable, there are questions that are waiting to be answered: will NEOM follow the example of other specialised cities dependent on digital revolution? Because most of these cities or urban communities that were built following that example remain controversial and socially exclusive. These societies are mostly dependent on technological development rather than social development of the community. This mechanism enlarges, unfortunately, the gap between the different layers of the society, which leads to the creation of social bubbles and exclusion of some individuals or even social groups.

Will NEOM be able to apprehend social diversity or will it be for the elite, because its intended urbanisation pattern refers to pre-urban gentrification process? In February 2018, Reuters stated that the Saudi government started awarding contracts for $500bn targeting the development of a huge business zone in NEOM city. Moreover, the local construction companies were asked to build five palaces for the royal family. These palaces are the first to be built in NEOM's new huge business zone; they are going to be located at about 150 kilometres at the Red Sea coast west from the city of Tabuk (Reuters, 2018). The coast of the five palaces hasn’t been confirmed yet, but banks have been offering financing facilities to the construction companies. Reuters also added that palaces' architectural designs are to be modern Islamic and traditional-Moroccan styles. Helipads, a golf course and a marina are to be included in the palaces' complex (Reuters, 2018).

Will NEOM as a new community of social diversity -at the intersection between three countries- or as described: a new "hub of intelligence", a new "silicon valley", be able to receive all intelligence potentials with the same services and the same quality of life? Or, progressively will it transform to form a big bubble of social exclusion? Meaning that different social groups will isolate themselves into different clusters, based on their socio-economic status in order to subsist? The composition of its society evokes lots of questions about the behaviour of its inhabitants, their interactions and development.
Conclusion

"Sustainable communities are defined as ‘places where people want to live and work, now and in the future. They meet the diverse needs of existing and future residents, are sensitive to their environment, and contribute to a high quality of life. They are safe and inclusive, well planned, built and run, and offer equality of opportunity and good services for all’. Such a definition highlights the physical (here, urban) context in which communities exist” (Dempsey et al., 2009). As previously mentioned, the social pillar of sustainability is usually ignored or bypassed, making new urban communities prone to social exclusion, causing low liveability levels, which are also linked to the lack of good public urban spaces. In fact, the social/physical production of urban space is considered as a two-way process.

We believe that achieving a certain level of social sustainability in new cities can be a main actor for these cities to be more resilient thus more urbanely and economically sustainable (Mahmoud & Rashed, 2016). This means that each individual must have a role, place and space in the society from the beginning of the city's inception; each individual should be able to develop a sense of belonging based on his/her participation in a certain aspect of community building; all the while taking sustainable development one step further towards regenerative development, which considers humans and their social structures as an innate part of the city's ecosystem. Ultimately, to achieve liveability, a strategy of social integration and community building should be devised during the conception of a new urban community: a strategy that is evolutionary, adaptable and flexible; it should understand the diversity of each place, socially, culturally and environmentally, while seeing the design process as ongoing, participatory and indefinite (HCU, 2010).

While examining other examples of cities with urban social sustainability issues, one of the proposed solutions was to minimise underutilised areas in urban surroundings through transforming them into mixed-use spaces that promote safety, social mixing, social inclusion/cohesion, civic participation, equity, recreation and a sense of belonging; thus, achieving urban prosperity.

Also, public spaces that are well designed/managed contribute to eco-environmental sustainability, improvement of public health, transport efficiency, as well as to equally serving all inhabitants from various genders and ages.

Finally, conceiving high density cities that contain a variety of programs and neighbourhoods/clusters that promote walkability, while avoiding generic spaces, are more liveable, encourage healthy evolution, and discourage sprawl. In order to achieve urban social sustainability in the era of digital technology, such concepts must be incorporated in the local physical development plan of the new city from the very beginning.
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Sustainable Urban Design Patterns in Arid Regions and its Comparison with Modern Patterns: the Case of Riyadh City

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Abstract: Saudi Arabia has witnessed a great development boom over the last few decades as a result of the oil discovery. This development boom has led to many environmental, social and economic changes, some of which are positive and others are negative due to not taking into account the specific characteristics of arid regions. Indeed, the current development manner has changed the urban pattern in many cities as a result of importing foreign urban patterns that are not compatible with the local conditions of these areas. Some argue that this was a natural consequence of the steady increase in population and rural-to-urban migration to obtain better livelihood opportunities in the large cities. However, in this paper, it is argued that when thinking about making the desert, which constitutes the majority of the Arab lands, a suitable ground for accommodating urban expansion, this is done only by studying the characteristics of the desert environments and studying what suits them from the urban patterns. The aim of this paper is to investigate the urban pattern of arid regions, and selected is Riyadh, the capital city of the Kingdom of Saudi Arabia, as a sample of these areas which is characterized by special climatic conditions. Additionally, the current urban pattern in Riyadh was investigated and compared with the traditional one in the past in order to highlight the best practices to deal with such environments and can be applied globally with some adjustments. The study shows that more research of the concept of urban development in the arid regions is needed to be carried out.

Keywords: Desert areas; arid regions; compact planning; urban pattern; Kingdom of Saudi Arabia; Riyadh.

Introduction

The Kingdom of Saudi Arabia has witnessed a great development boom over the last few decades as a result of the oil discovery and the production of commercial amounts of crude oil. This development boom has led to many environmental, social and economic changes, some of these changes are positive and others are negative due to not taking into account the specific characteristics of arid region environments. Indeed, the current development manner has changed the urban pattern in many of Saudi cities as a result of importing foreign urban patterns that are not compatible with the local conditions of these areas. Some argue that this was a natural consequence of the steady increase in population and rural-to-urban migration to obtain better livelihood opportunities in the large cities.

However, in this paper, it is argued that when thinking about making the desert, which constitutes the majority of the Arab lands, a suitable ground for accommodating urban expansion, this is done only by studying the characteristics of the desert environments and studying what suits them from the urban patterns. The aim of this paper is to investigate the urban pattern of arid regions, and selected is Riyadh, the capital city of the Kingdom of Saudi Arabia, as a sample of these areas which is characterized by special climatic conditions. Additionally, the current urban pattern in Riyadh was investigated and compared with the traditional one in the past in order to highlight the best practices to deal with such environments and can be applied globally with some adjustments.
In this paper, the analytical descriptive method was used in order to achieve the aim of this study. The paper is divided into three main parts, in the first part; the paper presents a literature review about the arid regions related studies including the features and urban patterns of these environments. The second part presents an empirical analysis of the pace and size of urban growth in Riyadh during the last hundred years and compares the current urban pattern in the city with the traditional one in the past. Finally, the third part of the paper highlights the main findings of the research and presents some key recommendations to be followed in the arid region environments during the urban development processes.

**Features of Arid Regions**

Technically, Alshuwaikhat and Nkwenti (2002) pointed out that the arid regions globally include those located within the equatorial belts of the world, universally referred to as hot deserts, and those located within the tundra belts, otherwise referred to as cold deserts. These include the Arabian, the Saharan and the Atacama deserts. The climate of the hot deserts areas, which are the focus of this study, is characterized by high temperatures in the summer, where the maximum temperature of the shade rises to 45°C, and sometimes reaches 50°C, and the lower end of the heat at night does not fall below 20°C. Indeed, the challenges in most desert areas stem from extreme temperatures that are characterized by high diurnal ranges, occasional sandstorms, and shifting sand dunes.

Most of the major deserts of the world (e.g. Saharan, Arabian, and Australian deserts) have some of the most rapidly growing population rate in the World (8.3%), and often of a relatively young age, all gravitating towards urban centres (Alshuwaikhat and Nkwenti, 2002). Moreover, Hall and Tewdwr-Jones (2010) points out that these arid regions approximately have a 5% urban growth rate, which is likely to double in the next 13 years. In the same context and in order to obtain better livelihood opportunities, the urban areas located in these regions are currently facing many waves of immigration where the number of the population is on the rise in many urban areas as highlighted by the United Nations in 2012 (ALQahtany, 2013).

**Urban Patterns in Arid Regions**

Throughout the ages, the urban patterns have always been a true reflection of the civilized environment that prevailed at each successive stage of history. From ancient times, many cities rose on the edge of the desert, where the warm environment helped its natural and social conditions to create a certain pattern suited to it. For instance, the warm environment has directed people to the interior, whether in the design of houses or neighbourhoods or even the city as a whole in order to provide protection against climatic conditions. Different urban pattern formations appeared at the level of planning in arid regions in a spontaneous manner without prior studies of the planning elements that fit with these environments or even studies of spatial relations between these elements. However, these traditional patterns truly reflect the function and the natural, cultural and social environment, as they have been able to achieve sound urban solutions that can protect against extreme weather conditions.

As a result, the compact buildings appeared in a random fabric and wrapped around interior spaces of their buildings, which acted to provide the largest shaded area. This integration and overlap of spaces is seen as one of the most important planning and design values of the traditional urban environment. This organic planning works to reduce the exposure of its various components such as housing, streets and corridors to a large amount
of external environmental effects such as direct sunlight, heat transmitted by radiation, or dust in the air. Therefore, many studies (Khalissa and Said, 2007, Pearlmutter et al., 2007, Monshizade, 2008, Maleki, 2011, Eltrapolsi and Altan, 2017) point out that the adoption of a compactly urban patterns or what is known as “compact city” is most appropriate in desert climates in order to minimize the effects of exposure to external climatic conditions.

Compact Planning

Jenks and Burgess (2000) offered a definition of compact city approach: “to increase built area and residential population densities; to intensify urban economic, social and cultural activities and to manipulate urban size, form and structure and settlement systems in pursuit of the environmental, social and global sustainability benefits derived from the concentration of urban functions”. However, in order to be more specific in this paper, the idea of the compact urban patterns will be discussed in the light of the local context of the arid regions. The compactness of urban texture in a hot dry region “contributes to the thermal protection because the narrow winding streets are partially covered; the urban structure is usually a continuous pattern” (Scudo, 1988). Indeed, a compactly built urban environment has advantages for pedestrian comfort under hot and dry conditions, and it has been underlined by the experimental results of several recent studies (Ali-Toudert et al., 2005, Johansson, 2006, Pearlmutter et al., 2007). One of the most important features of this urban style is that the streets are narrow and curved to reduce areas exposed to the sun, which works to stabilize the thermal and keep the cold air down the streets.

In compact planning, urban patterns can be divided into two main types: vertical compact planning and horizontal compact planning. The vertical pattern means the vertical extension of buildings in which it reaches high elevations levels (four floors and more). Unfortunately, this is the pattern in most arid regions, although the negative aspects of this type overcome the positives, for example, most of the facades and surfaces of these high buildings are directly exposed to the different climatic factors of these environments. The horizontal mode of urbanization takes into account the horizontal spread mode so that the buildings are spread horizontally and at a low high not exceeding four levels maximum. In this paper, it is argued that horizontal compact planning is the most appropriate for the arid regions, particularly the pattern of horizontal building oriented to the inside, where it provides more protection against the different conditions of this harsh climate. Therefore, this paper will focus mainly on clarification of the horizontal compact planning and identify its types as well as the pros and cons of each one in order to identify the suitability of each of them to the desert climate and access to the optimal pattern.

Horizontal Compact Planning

The horizontal compact planning in this paper means the spread of urbanization horizontally so that the buildings are spread horizontally and at a low high not exceeding four levels maximum as mentioned earlier. This type of planning divided into two patterns: horizontal urban pattern oriented outward and horizontal urban pattern oriented inwards. Several studies (Mohamed, 2002, Al-Hathloul, 2003, Gamboa, 2008, Middleton, 2009, Al-Kaabi, 2011) have studied these two types of horizontal compact planning and compare them based on several criteria according to the purpose of each study. However, this study identified 9 criteria that were used mainly to compare these two types as presented in Table 1, which were obtained through reviewing and analysing the previous relevant studies.
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<th>Comparison criterion</th>
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<tr>
<td>Compatibility with the desert</td>
<td>Compatible where the inner courtyard of the house acts as a regulator of the temperature inside</td>
<td>Not compatible where the houses are exposed to dust storms and solar radiation more because most of</td>
</tr>
<tr>
<td>environment</td>
<td>the dwelling day and night and achieves ventilation and protection from wind and storms</td>
<td>the façades and external surfaces are directly exposed to external factors.</td>
</tr>
<tr>
<td>Achieving privacy</td>
<td>The presence of the inner courtyard provides more visual and audio privacy than the external</td>
<td>Directing the spaces outward and near the buildings from each other work to reduce the level of</td>
</tr>
<tr>
<td></td>
<td>courtyard.</td>
<td>privacy.</td>
</tr>
<tr>
<td>Insulation from noise</td>
<td>The inner courtyard provides a quiet space inside the dwelling as the walls act as a buffer against</td>
<td>Buildings of this pattern are subject to external noise directly as a result of their outward</td>
</tr>
<tr>
<td></td>
<td>external noise.</td>
<td>orientation.</td>
</tr>
<tr>
<td>Streets</td>
<td>Streets are not straight, narrow, and are closed-ended in most cases, which reduces the speed on</td>
<td>Streets are straight, wide, parallel, and are not closed-ended, which increases the speed on them</td>
</tr>
<tr>
<td></td>
<td>it and thus enhance the movement of pedestrians</td>
<td>and reduce the pedestrian movement.</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>This pattern provides safe pedestrian corridors that are protected from sunlight.</td>
<td>Lack of safe pedestrian corridors, whether from traffic or sunlight.</td>
</tr>
<tr>
<td>Open spaces</td>
<td>Space hierarchy is clear, where there are semi-private spaces strengthening the links between</td>
<td>Spaces hierarchy is not clear and there are no semi-private spaces strengthening the links between</td>
</tr>
<tr>
<td></td>
<td>inhabitants.</td>
<td>inhabitants.</td>
</tr>
<tr>
<td>Level of safety</td>
<td>Level is high due to narrow streets that reduce the speed of vehicles and provide safe</td>
<td>Safety level is low due to the lack of private spaces where the wide streets increase the movement</td>
</tr>
<tr>
<td></td>
<td>corridors for pedestrians and safe spaces in which children can play away from the streets.</td>
<td>that crosses these areas and poses a threat to the residents, especially children.</td>
</tr>
<tr>
<td>Social side</td>
<td>This pattern promotes social aspects by providing internal spaces that enhance social relationships both outside and inside the home.</td>
<td>This pattern reduces social interaction due to the lack of social spaces that help to strengthen social relationship.</td>
</tr>
<tr>
<td>Economic side</td>
<td>The demand for energy is less because of the internal courtyards that act as a thermal regulator in addition to providing the natural light.</td>
<td>Demand for energy is more as most of the building facades are exposed to sunlight and thus increase the demand for air conditioning and lighting.</td>
</tr>
</tbody>
</table>
Riyadh City

In the last 80 years, Saudi Arabia became the most important oil-exporting country in the world due to the discovery of its rich oil reserves. Indeed, the establishment of the oil industry over the past few decades led to an economic boom that changed the kingdom into a modern developing country (Mubarak, 2004). As result of that Saudi cities in general and particularly Riyadh city have witnessed a significant growth in the field of urban development. Riyadh city, which is the emirate headquarters and the capital of the Kingdom of Saudi Arabia, is located in the middle of the eastern part of Riyadh Region. In less than half a century, the area of Riyadh has grown and expanded more than a hundred times from a small mud-walled town to a modern and global metropolis that occupies an area of 2435 square kilometres (ADA, 2010). The population of the city has risen dramatically from 100,000 in the early 1950s to almost 5.2 million people in 2010, which is equivalent to approximately 22.36% of the total population of the Kingdom of Saudi Arabia (General Authority for statistics, 2012, AlQahtany et al., 2014).

Due to its significant expansion in numerous fields, Riyadh city is generally considered the largest Arab city, and also seen as one of the fastest developing cities in the world (AlQahtany et al., 2014). The city lies in the centre of the Arab Peninsula, located at latitude 34°-38 north, longitude 46-43 east and approximately 600 meters above sea level (Riyadh Municipality, 2011). Riyadh is characterized by its arid climate and having a hot desert climate where during the summer months temperatures are extremely hot. In August, for instance, the average high temperature is 45 °C. Moreover, Riyadh is known to have dust storms during which the dust can be so thick and affects visibility, for example, in April 2015, a huge dust storm hit Riyadh, causing suspension of studies in all schools and universities in addition to the cancellation of hundreds of trips, both local and international.

The Urban Structure of Riyadh during the Last Hundred Years

The urbanization process of Riyadh offers a unique situation in which the city urban morphology can be examined in light of economic and socio-political conditions (Mubarak, 2004). Several studies (Al-Hemaidi, 2001, Al-Hathloul, 2003, Garba, 2004) point out that at the beginning of the twentieth century Riyadh began its growth as a modern city when it was reinstated by King Abdul Aziz bin Abdul Rahman bin Faisal Al Saud (known universally as Ibn Saud) the founder of the Third Saudi State. At that time, the city covered an area of almost one square kilometre and the population was approximately 8000 people (Riyadh Municipality, 2011). The city was enclosed by impervious walls built by using bricks and mud and enhanced with fortified gates almost eight meters high (Figure 1).

At the beginning of the 1930s, Ibn Saud unified all the regions of the Third Saudi State under the banner of one country (known today as the Kingdom of Saudi Arabia) and as a result of that the population of Riyadh grew rapidly from almost 15000 in 1918 to 47000 in 1938 (ADA, 2013). At the end of the 1930s and as a result of the population growth Riyadh expanded outside the mud walls of the old city for the first time. This expansion was demonstrated by the construction of Qasr Al-Murabba (Al-Murabba Palace) north of the old city of Riyadh. Al-Hathloul (2003) point out that the building of Al-Murabba Palace had a strong impact on the growth and physical development of Riyadh, where the city expanded noticeably. According to Alkhambuz (2010) the discovery of the oil at the end of the 1930s and the production of crude oil in the 1940s in commercial amounts began an urban revolution in Riyadh in particular and across the Saudi cities in general. During the 1950s
and 1960s, the construction of Al-Nasiriya Palace (west of the old Riyadh at Al-Nasiriya Farm) and Al-Malaz project (northeast of the old Riyadh) contributed further to the city's expansion horizontally in all directions. Middleton (2009) points out that Al-Malaz project covered an area of approximately 500 hectares involved 750 villas, three apartment buildings, and facilities.

![Figure 1](image1.png)

**Figure 1** A layout plan of the traditional urban form of old Riyadh as a walled city. Sources: Gamboa (2008).

Until the early 1950s, the spatial formation of the old Riyadh is characterized by small neighbourhoods composed of blocks of houses that reflect a composition of rectangular buildings with an interior courtyard covers the whole plot (Al-Hathloul et al., 1975). The depth of the building around the courtyard is approximately 3 to 4m and usually the plot dimensions are 10m x 10m or 10m x 12m. Furthermore, “in the 1950’s mud brick construction materials were replaced by concrete, a trend that was becoming one of the greatest influences affecting the planning of residential communities” (Middleton, 2009) (Figure 2).

![Figure 2](image2.png)

**Figure 2** Traditional form of the spatial structure of the older districts of Riyadh. Sources: Doxiadis (Associates, 1977).

According to Al-Hathloul (2003), Al-Malaz project had a great impact on the architectural and urban pattern of Riyadh, and it introduced a new way of thinking in terms of planning and construction. The adoption of the gridiron planning in Al-Malaz project was a clear departure from the traditional urban pattern of Riyadh, which was characterized by a labyrinthine urban pattern, as is the case with other traditional Islamic cities (Musa and Al-Asad, 2003). By the late 1950s, the construction of multi-story buildings started to spread in Riyadh as result of the city growth. Among the first apartment buildings that were
constructed in Riyadh in the 1960s, were the six-story building of Fahd bin Muhammad, which overlooked Al-Adl Square, and Zahrat Al-Riyadh Building, which was situated at one of the corners of a crossroad (Figure 3). However, in the design of these multi-story buildings, the issue of privacy has been taken into account, and the buildings were designed to have views on public areas, such as streets and squares, not on close family houses. Indeed, buildings sides that faced neighboring houses were retained for staircases and services, and window openings there were limited and located above eye level in order to protect the privacy of the neighbours (Musa and Al-Asad, 2003).

During the 1970s and 1980s, Riyadh witnessed an enormous construction boom as a result of the increase in oil prices. In fact, Newsweek Magazine described Riyadh at that time as “the biggest construction site in human history”, especially, during the decade extending from 1977 to 1986 when an average of 11,500 building permits were issued in Riyadh each year (Al-Hathloul, 2003). Until the middle of the 1980s, a number of projects have been constructed in order to cope with the city's rapid growth, and most of these projects were inspired by the local urban heritage of Riyadh, which aimed to develop new urban patterns that blend the old with the new, such as the Diplomatic Quarter and the Ministry of Foreign Affairs Staff Housing (Figure 4).

During the 1990s, many modern projects emerged, which were designed by many international consulting firms such as the well-known British architect Norman Foster and Partners who designed Al-Faisaliah Complex finished in 2000 and the American firm Ellerbe Becket who designed the Kingdom Centre finished in 2003 (Figure 5). Obviously, both Al-Faisaliah Complex and the Kingdom Centre depart from a traditional urban pattern to a more or less global one, which undoubtedly, have impacted urban pattern directions in Riyadh in particular and in the other cities in Saudi Arabia in general (Al-Hathloul, 2003, Musa and Al-Asad, 2003).
Comparison of the Urban Pattern of Riyadh in the Past and the Present

In order to achieve the main aim of this study, which is to formulate a number of strategies for a sustainable urban design of the arid regions in KSA through studying the urban pattern of Riyadh, the study compared the urban pattern of the city in the past and the present. This comparison aimed at finding the best practices and methods to deal with such an environment. The comparison will be mainly based on the 9 criteria that were identified throughout the review of the related studies and literature and discussed early in this paper, which are 1) compatibility with the desert environment; 2) achieving privacy; 3) insulation from noise; 4) streets; 5) pedestrians; 6) open spaces; 7) level of safety; 8) social side; and 9) economic side.

During the second half of the last century, Riyadh’s urban pattern had its own individual traditional characteristic which continued to prevail until the last few years when modern projects emerged. For instance, the projects of Al-Faisaliah Complex and the Kingdom Centre which are completely alien to the city traditional pattern. Unfortunately, a number of studies (Al-Hathloul, 2003, Al-Hemaidi, 2001, Alkhabbaz, 2010, Al-Qahtany, 2014, Gamboa, 2008, Mubarak, 2004) indicate that the successful examples of the adoption of the traditional urban pattern in Riyadh are very few. One of these examples is the Ministry of Foreign Affairs Staff Housing, which took into considerations the local climate of Riyadh and the urban form of the traditional neighbourhoods. One of the main reasons for this issue is that modern urban planning in most of the Saudi cities was implemented on the basis of Western methods by foreign consultants. Indeed, it has been designed in a random manner and managed without referring to the local regulation (Brebner, 1988).

Most of the existing buildings in the city have been designed in a way that is not suited to the local climate, such as using of a glazed curtain wall to cover whole façades of buildings regardless the hot climatic conditions. This obviously is the case with the design of Al-Faisaliah Complex and Kingdom Centre highlighted previously. Moreover, most of the buildings are designed to be exterior oriented, unlike in the past, where buildings were designed to be interior oriented around an inner courtyard (Figure 6). Undoubtedly, following the internal oriented approach in designing the buildings is considered one of the best practices in desert environments in term of dealing with climate conditions and protecting the privacy of residents.

With respect to the issue of privacy and the changes that have been occurred in the past few decades, the design of the high buildings in the city ignored the visual privacy of
residents of neighbouring housing and apartments in the absence of the regulations that protect the visual privacy rights of them. This obviously is the case with the design of the Fahd bin Muhammad's and Zahrat Al-Riyadh apartment buildings, which discussed earlier, that violated the privacy of the neighbouring houses, especially with the outward-oriented design and the disappearance of the internal courtyard of buildings. This has led many residents to use some construction techniques to maintain their privacy, such as the use of high-wall panels as shown in Figure 7. However, the construction of these buildings became more and more ubiquitous as a result of the urban growth and development that continued at a very fast rate across the city Al-Hathloul (2003).

![Figure 6](image1.png)  ![Figure 7](image2.png)

Figure 6  An examples of the traditional internal courtyard of buildings that were existed in the past.
Source: Al-Kaabi (2011).

Figure 7  Placing panels above the walls to achieve privacy among neighbors.
Source: Mohammed (2002).

Some argue that although the traditional urban pattern of old Riyadh resembles urban patterns in other old Islamic and Arab cities in term of its compact and low profile buildings, the urban development of Riyadh during the 1980s and 1990s, particularly the modern grid pattern, was untraditional-conscious. Indeed, the adoption of the gridiron pattern in Riyadh has led to a phenomenal horizontal expansion which has created thousands of hectares of subdivisions that are inappropriate and scattered around the periphery of Riyadh and resulting in a very low density of population (Figure 8).

The parallel street network has overcome the design of the city's road network as a result of the grid planning, where there are many parallel and not closed-end streets. This is certainly different from what it was in the past where the traditional built environment was characterized by the narrow, shaded and closed-end streets which in fact provide safe spaces in which children play away from the streets. Unfortunately, the current pattern of the road network in Riyadh increases the vehicle speeds not only at the city level but also in residential neighbourhoods, where there are no clear pedestrian paths due to the wide streets that penetrate the residential neighbourhoods and reduce the level of safety. According to Al-Ahmadi et al. (2009) the Doxiadis plan of Riyadh concentrated on the
division of the city into several neighbourhoods with 4 square kilometres total area for each one, and considered the car as the primary means of transportation within the city.

Figure 8 The random expansion of the gridiron subdivisions in the city of Riyadh during the last a few years.
Sources: Mubarak (2004).

In general, the current urban pattern of Riyadh is not compatible with the local environment of the city, as it is characterized by sparse horizontal growth, unlike the compact urban fabric in the past. In this pattern, many important aspects of the lives of the population are not considered. For instance, this pattern worked to dismantle the social ties due to the distances between the city parts, and the lack of spatial spaces within the city that give the residents a greater chance to meet and get in touch. Additionally, this type of patterns is not economically sustainable where the expansion of the city in this manner increases the cost of infrastructure and transportation. This, without doubt, affects the daily lives of the city and its inhabitants in many ways including the rising of different types of pollution whether noise or air pollutions arising from the huge number of cars.

Conclusion and Recommendations

In recent years, people may have learned about the negative sides of foreign interventions in the development of their cities including the overlook of the significance of the traditional urban textures which can be protected from disappearance by considering the forgotten aspects that was referred to in this study. The aim of this paper was to investigate the urban pattern of Riyadh, which presented as a sample of arid region environments that are characterized by harsh climatic conditions, and compare it with the traditional one in the past in order to find out the best practices to deal with such environments. Based on the findings of this study, there is no doubt in concluding that the current urban pattern of Riyadh departs from the traditional pattern to a more or less global one due to the implementation of foreign models without studying the local environment properly. During this study, it was found that the horizontal compact planning, which oriented inwards, is the most compatible pattern with the desert climate. The outward-oriented urban patterns, including the gridiron one, do not correspond to the desert climate and also not achieve the required privacy of the inhabitants.

Moreover, streets and roads in gridiron pattern became a parallel network serving the car in the first place and it ignored the importance of the pedestrian, thus, it does not assure the safety of the inhabitants, particularly the children, because of the movement of vehicles is not separated from pedestrian paths. The outward-oriented pattern also does not match economic factors due to the increased demand for energy as most of the building facades are exposed to sunlight. On the other hand, the inward-oriented pattern was found to be more compatible with the desert climate due to its openness to internal courtyards that provide ventilation for elements of the dwelling and protection from hot winds and
sandstorms. The urban fabric in this pattern is compact and thus leads to increased density. It is also compatible with social factors, where it achieves privacy and strengthens social ties. This pattern also provides a safe place for people to meet and for children to play as a result of the possibility of separating the movement of cars from pedestrians. Finally, this paper concludes with a number of important recommendations that are needed to be followed when starting the process of developing cities characterized by the arid climate. These recommendations are:

- During the development of desert cities, the importance of using the compact urban pattern needs to be taken into account.
- Emphasizing on the importance of using the internal oriented approach in designing the buildings in desert environments to deal with climatic conditions of these environments.
- The urge to take into account the social dimension during the process of development of desert communities through achieving the required privacy of the population both inside and outside the house.
- The need to observe the separation of pedestrian paths from cars movement, and provide the necessary spaces to meet the needs of the inhabitants and enhances the social ties between them.
- Taking the environmental dimension into consideration by taking care of the materials used in the facades of buildings and away from materials that may not be suitable for desert environments such as glass and aluminum.
- Taking the economic dimension into account by taking care when expanding the city horizontally, and plan thoughtfully away from the randomness that increases the cost of infrastructure and transportation.

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“Contextual Urban design approaches – Sustainable Built Environments.”

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Abstract:
UN 2018 report says that 55% of the world’s population lives in urban areas, a proportion that is expected to increase to 68% by 2050. With present hegemony of global development framework is a concern; as majority of the built mass is to be built in developing countries. Such an approach has created vast building stocks largely not in sync with the local geographies /ecology. Driven by capitalism they are built for financial gains to benefit a selected few and more often, not within the reach of masses. The global architectural vocabularies of glass façade buildings are high on energy consumption and such built environs being built and continuing shall have a huge impact on climate change and thereby sustainability.

Interestingly most of global south especially Asian cities have backdrop of developments that are centuries old and have sustained except for the nature of development in the recent past. Typically each of these urban developments is strongly underpinned by the local cultures that have evolved over centuries are inherent to the local resources for all pillars of sustainability. Thus at this point in time it may be worthwhile to reexamine these urban design approaches that vouched for an application of nature’s law and patterns of systematic socio-cultural reinforced by religion using indigenous practices with regenerative economies that are distinctive and robustly contextual. The aim of the paper is to examine a typical contextual urban design approach that is sustainable and climatic responsive; characterized by an archetypal built morphology resilient to contextual socio-economic and environmental framework. The expected outcome of the paper is to bring on table a case study of typical contextual approach that thrived for centuries and responded to all pillars of sustainability for almost three centuries and continuing.

Key words: Urban design approaches, context, Sustainability, Climate change and Jaipur city.

1.0 Introduction
The 2018 Revision of World Urbanization publication says that together India, China and Nigeria shall account for 35% of the projected population growth globally between 2018 and 2050. India will add 416 million urban dwellers, china 255 million and Nigeria 189 million. (UN 2018) Also in 2017 (IEA) the growth of global energy demand was concentrated in Asia with India and China together representing more than 40% increase. Overall Asian economies accounted for two-third of global increase in carbon emissions. In India per-capita emissions was 1.7 tCO₂ well below the global capita average of 4.3t CO₂ rising energy demand is a grave concern especially with rapid urbanization on.

This fast urbanization calls for large-scale developments thus pressure on construction sector. Although these developing nations are experiencing rising economies but to keep pace with the rapid growth, the governments are involving the private sector as well. While for the private players profits are key thus they invest in office, retail, high-end housing and other such projects; typically characterized by the tendency of glass façade high tech buildings copied representing global image irrespective of local ecologies. Such type of development in the name of urbanization shall lead to explosion of embodied energy in the usage of timber, steel, concrete, paints and others that is environmentally unsustainable. Thus large building stocks are standing, majority are bought essentially for speculation purposes but not occupied as they are beyond the affordable limits of the masses. The dichotomy of economic efficiency over social equity leaves mass housing as government’s responsibility. Such an imbalance in
development pattern is not sustainable. Therefore for sustainable urbanisation successful development is the key and as the construction sector is expanding, all the more reason to monitor the nature of development to be sustainable.

As per Joseph (JD) D’Cruz (Senior Advisor, Strategy and Planning at UNDP) “Urban growth is mainly in the Global South, but most of our tools and frameworks for urbanization were developed in the north.” To tackle such a situation we need to rationalize in our approach to sustainable urban built environs.

The objective of the paper is to establish the significance of a contextual urban design approach that thrived with time, exhibiting the inherent resilience to socio-economic setup for the local ecology translated such in an archetypal built environment that was/is sustainable.

2.0 Understanding Urban design:
Conventionally urban design is perceived as an amalgamation of several disciplines, including architecture, landscape architecture, urban planning and civil engineering. Quite aptly put as an understanding of urban design primarily as a finished product (instead of long term process intertwined with social and political mechanism) and a pedagogical process that is comfortably rooted in architecture and design (Inam.A, 2002). Therefore it is important to understand Urban design not as an intermediate scale between architecture and city but a comprehensive, more organic in nature that has inherent resilience because of dynamic relationships among the aspects and their sub-aspects. Even Gosling (1984a, b) suggests urban design is concerned with the limited physical area of the city and therefore lies between the two well-established design scales of architecture.

As per American literature on contemporary practice of urban design, according to Barnett (2003) began in the 1960 as reaction against the failures of modernism to produce a livable environment. To make cities more livable, urban designers countered modernist ideology by protecting historic buildings, by making the street the primary element of urban open space, and by using zoning and other development regulations creatively to put new buildings into context and preserve a mix of different activities (Barnett 2003). While some urban geographers (Scargill 1979; Foley 1964) looked at urban form from morphological point of view, i.e., its physical fabric, office and manufacturing functions, and the assemblage of structures that are the spatial expression of urban phenomena, such as economic, social and political processes. Christopher Alexander (Alexander et al. 1987) in his “A new theory of urban design” considered the laws of wholeness as the main quality of urban design; stressed on processes and evolution of built environs such. While analysis of urban patterns by Kostoff through his two books (The city shaped 1991; and The city assembled, 1998) elevated the understanding of urban design at another level. Next Hertzberger (1991) suggested that just as mankind is distinguished by its use of language, so too does mankind have the facility to adopt and give meaning to spaces, not to be governed by an individual, but negotiated socially. Among the non-planners from Maslow and others to Amos Rapport of the writings on the mutual interaction of people and their built environment: A cross-cultural perspective (1976). Also learning’s from Howard. E- garden city, Olmsted .F. central park NYC to Space syntax by UCL, and others added specific dimensions to the core understanding of urban design. Thus, rightly put across by Richard Marshal (in Krieger et al. 2009) suggests the definition for urban design in ‘The Elusiveness of Urban Design’: “Urban design is a ‘way of thinking.’ It is not
about separation and simplification but rather about synthesis. It attempts to deal with the full reality of the urban situation, not the narrow slices seen through disciplinary lenses.”

**Urban design theories:**
Royal Institute of British Architects (1970) advocates that major characteristic is the arrangement of the physical objects and human activities which make up the environment; this space and the relationships of elements in it is essentially external includes a concern for the relationship of new development to existing city form as much as to the social, political and economic demands and resources available.

Over thirty years ago Pittas (1980) emphasized on the importance of a clear definition to the success of the profession. He, then, suggest seven parameters that urban design deal with: (1) enabling rather than authorship; (2) relative rather than absolute design products; (3) uncertain time frame; (4) a different point of entry than architecture; (5) a concern with the space between buildings; (6) a concern with the three dimensional rather than two dimensional, and (7) principally public activity. (Bahrainy.H; Bakhtiar .A 2016)

A broad mapping the urban design approaches, their application and continuing, are adapting to the changing needs of the global cultures in parts or whole. While Araabi (2016) puts across pragmatically- a concise of urban design theories as summed up: subjects, objects and knowledge by are three theories and over timeline observed as layers in urban design approaches are as follows:

- **Theory about subjects** within urban design: about composition of mass and space; about visual aspect of townscape, about image of a city, about safety, social interaction and about identity, history and meaning of cities.
- **Theory about objects** of urban design: while type one is seen as theories in urban design and type two as urban design theories of urban design. Comprehensive view – place making.
- **Theories about knowledge** of urban design: urban design derives from both spatial and social processes; theorizing from perspective of other disciplines usually social sciences.

The various development layers perceived as traditional, historic, regionalism to modernism/post-modernism have added contextual dimensions to urban design. And comprehensive understanding has brought paradigm shift for example from sociology to anthropology and others, redefined by technology for subjects, objects and knowledge at large.

**3.0 Urban design and context:**
Repeatedly in urban design literature various contextual connotations have been debated and relevance of each one established such. For example: Critical regionalism also tries to find a design to suit the identity and potential of the site. The main concern of the movement’s was to oppose universalism and inhumane, technocratic architecture. Their aim was to produce a form, which brings out whatever made the site different from all others (Voordt & Wegen, 2005) In his work "Towards a Critical Regionalism: Six points of an architecture of resistance” Frampton (1983), criticises and discusses not to reject modern architecture but integrates it with contextual perspective, the integration of regional values (cultural identity) into the contemporary language of form. Uraz, Pulhan & Ulucay (2010) talks of the corresponding architectural changes throughout this period; discusses how Regionalism gives importance to
local identity and culture, and how together with most notably modernism, has a reaction to traditionalist and historical inclinations. Architects such as Aalto, Pietila, Jocabsen, Saarinen and Utzon local identity took placement at the forefront; and as a result, a more responsive reaction has been attained towards modernist, traditionalist and historical approaches. Regionalism is an architectural movement that advocates using local materials and tectonic practices in combination with building forms that are attuned to immediate environmental conditions, to create a contemporary, but still recognizably vernacular architecture; a vocabulary that reinforces contextual connotation. The contemporary backdrop of Global cultures & Urbanisation, the urban change is fundamental, covering demographic transitions, global economic and financial integration, institutional reforms, and the tensions between the causes from private sector growth and improved socio-environmental development. In local contexts, the new environmental planning and management occurs where inequality of power among government agencies, community groups and other stakeholders is the norm. (Jorge.E.H, Mitlin.D and Satterthwaite.D; 1992)

Locally owned businesses contribute more to economic cultural stability of the community than trade name, chain stores etc. (Kennedy, Smith: 2000) Such social set ups takes years to build invariably they are a part of larger ethnic communities typical for a region. That a cohesive ethnic base is required for a city neighbourhood, that works as a social unit and thus shear ethnic identity is a significant factor. It typically takes away many years after such groups have settled in for time to work and for the inhabitants to attain stable, effective neighbourhood. Laid strong emphasis on mixed land use, smaller blocks with an opportunity to turn to corners must be frequent, need for aged buildings. (Jacob;1961) The study of historical continuity, contextualism also became an important concept for the establishment of city unity; appearing not only in architecture but within urban design also Many theorists including Lynch (1960), Gordon (1961), Rossi (1984), Rowe & Koetter, (1984), Venturi (1983), Gandelsonas (1998) and Nesbitt (1996) all addressed the commotion in the city by redefining the city itself. Schumacher cited in Nesbitt (1996), also puts forward a similar view in his work “Contextualism: Urban Ideals and Deformations“. In addition to analysis of the unity that comes from traditionalist approaches, he examines and compares the modernist attitude to that of the traditional city. He notes that while the traditional city, defined with its continuous walls of buildings, establishes harmony within its spaces and city unity, the modernist is in complete opposite, .....place theory is highly concerned with the regional, street and city historical and current expressions and meaning. Beaver(2007) give attention to this issue under the heading “Contextual intervention: a sense of place”: The streets and public spaces of the city are defined by the facades of the buildings that surround them. The exterior wall is the element that mediates between the two – between the public realm, whose edges it defines and the private realm, whose domain it encloses (ibid).

4.0 Contextual Urban design and Sustainability:
The contextualism is strongly ingrained for all pillars of sustainability for example a layered approach to design determined by geographical context was strongly demonstrated by McHarg whose significance has got recognized especially with current global planning practices- an environmental approach. While a decade later the significance of streets that focused on the social aspect by Jane Jacob have gained importance once again in the world of internet wherein
the social connotation is getting diluted gradually and defensible spaces by Oscar Newman focus on inherent security issues- a social-cultural connotation. Next almost three decades later Harvey explored the meaning of history geography and culture on social production of space and time and how nature and environment have been understood and valued in relation to processes of social change and others- a socio-economic connotation.

As the developing countries are at varying thresholds of development essentially because of their respective contexts and urbanising fast it is an opportunity for the planners to navigate in sustainable direction. Further the scale of urbanisation have cities expanding exponentially i.e. in the name of transit oriented development the urbanisation has assumed new scales. Currently the towns and cities are urbanising the fastest as compared to the metropolitan cities, a strong reason to monitor the nature of development in these cities.

Each of these cities was planned differently, reflecting the differences in the political and social systems as well as in the cultural values. Yet, their built urban environment being responsive to human scale characterizes all the great cities of different civilizations. Streets are tight-knit and compact, planning layouts are complex and textures of buildings are rich. There has been a paradigm shift from community building to individual’s whim to build, which cuts across the bond between environment and architecture enjoyed by the regional context. 1994 Lang according to contextual design is the most important element in urban design because without context, the city becomes fragmented. Lang examines the social and environmental issues within the context of urban history. The future of our architecture and built environment must reset with those who will and can introduce a more humanistic approach, responsive to both the religious and ethical identity. [Lim; 1990]

Barnett. J (2003) Urban Design stressed on to have knowledge of social sciences with new urbanism vouching for mixed land use with work and residence, typically inherent to traditional cities in Asia. Typical planning approaches always had a Pragmatic / adaptive approach; often characterised by interpretation of local/ regional values. With such an argument it is apparent that designing in relation to the context has existed for a long time; although the formal theory of ‘Contextualism’ have only existed in the last five decades. With Modernism/ post Modernism parallels were drawn with the local, traditional, historical designs thus not inherent to the contemporary approach. Rapid urbanisation, densities, global cultures and regular technological innovations essentially underpinned the shift. The practice of community participation in such cities is regulated by local cultures and largely continuing till date with no models to conceptualize, such heterogenic cities thus are largely self-referential therefore tradition matters. ( Menon. A.G.K; 2007)

Summing up for an urban design approach with sustainability indicators for environmental is limited by the geographical location with its climate, to the natural resources available within its surroundings- water, land, bio-diversity both plant and animals: species, land-topography at large. When walking was the mode of circulation, conventionally the cities extended to by 3-5 kilometers an inherent mechanism to control the scale of the city but with automobile mode the cities expanded to a certain limit essentially guided by the capacity to pay for the distance travelled. This demonstrates by got governing the paradigm shift in city limits socio-cultural to techno-economy.

New system in sustainability conversation aligned with wisdom of east/west indigenous systems; science integrated with systems / patterns vary for each of the context and have their
own tailor-made framework. Therefore it may be logical to conclude that each case to develop their contextual connotation within the broader global matrix. For example: Our economy may have recovered from the great recession but not our economies...for these indigenous models a new approach based on people to be developed; as human economy is embedded in biosphere. Such an approach to economy that has application of nature’s law and patterns of systematic religious, cultural, local socio-economic setup shall prove to be regenerative economy; recognizing human narrative while addressing market realities. (Bookstaber. R 2017)

Two-third of global wealth is human capital and acceleration in technology requires countries to invest in their people so as to compete in the economy of the future. The majority of the world population is young. (World Bank report; 2017) The younger generation is both technology savvy and forward looking thus more for global standards of living that is high on energy consumption. For example the result from simulations study on “framework to evaluate urban design using urban design microclimate modeling in future climatic conditions” confirmed that in the future there would be a constant decrease in the heating demand, while the cooling demand will be substantially increase. Significantly, It was further demonstrated that when the local urban climate was taken into account, there was an even higher rise in cooling demand. (Mauree.D, Coccolo.S, Perera.A.T.D, Nik.V, Scartezzini.J.L, and Naboni.E: 2018). Other than thermal comfort there are other dimensions as well that needs attention in a similar way and only then a comprehensive knowledge base that shall be case specific shall deliver for sustainability at large. The negotiation of global to context shall cover the gap and it shall be interesting to see the role of context for same geographies as well. It will be verified where an individual envelope strategy can neutralize the increase in cooling energy usage or a combination of several site based passive strategies may counteract the effects of climate change on cooling energy usage. (ibid)

5.0 Contextual Urban design approach – designing Sustainable framework for Jaipur
Conventionally the three pillars of sustainability – social, economic and environment were outlined to measure it. To this Physical factor was added to gauge the sustainability for cities. In 1997 UN set of sustainability indicators were gauged across the globe with feedback as well. Interestingly one of the key feedback was to add Culture as an indicator, which was added in 2006 UN set of sustainability indicators. This set of sustainability indicators was overlaid with contextual framework for a traditional historic city and applied for Jaipur. (Sharma. A.K, 2012)
With large number of historic cities in Asia the significance of contextual approach is highlighted. (Serageldin.I, Shluger.E, Brown.M.2001) The research objective has been achieved by empirically demonstrated for Jaipur for a period of 277 years herein. This framework has the potential to be duplicated for other such cities as well with contextual connotations tailored made for implementation at multiple locations to test its reliability and robustness. Jaipur also known, as pink city is a strong tourist attraction has hot semi-arid climate.

6.1 Original master plan as designed by Vidyadhar 1728:
The city of Jaipur was planned such as surrounded by rugged hills-north and east a natural feature accounted for protection for the city, situated on a ridge, which passes from east west across the city; has special advantage for natural drainage continuing till date. The nine square concept of Vastupurusha mandala from ancient Hindu scriptures, with each of the squares a social unit–neighbourhood. Each neighbourhood was characterised by hierarchy of streets, mixed land use and low-rise high-density building blocks with courtyards as only open spaces for the houses. Further the intersection of primary streets were main public spaces used for all social, economic and cultural activities.

Jaipur was planned based on town planning principles derived from the ancient Hindu scriptures: SHILPSASTRA: ‘Prastara’. Key Salient features as follows:

- Grid–iron pattern of streets with secondary and tertiary parallel to them.
- Drainage of streets worked out on natural slopes of land profile
- Mixed land use for main streets also accounting for future expansion.
- Social groups allocated neighbourhood based on their social stratification higher castes closer to the palace square: placed central to all the neighbourhood with lower castes located on the periphery, away from the central.
- Allocation of plots was planned out for example: prime location reserved for prominent persons and temples etc.
- The intersections of main streets: squares were designed for the people and have been used such; from water supply, circulation, interaction space, cultural/ religious gatherings to pedestrian/vehicular movement as of today.
- Quantification of building elements: plinth, entrances, fenestrations, heights etc.
- Approval from Vidyadhar the architect was a pre-requisite for construction.
- Use of locally available material red sandstone in lime mortar with indigenous technology primarily responsible for the built morphology.

As the city was built from scratch to build the socio-economic framework, invitation for the wealthy merchant, artisans, bankers, priests, and others were facilitated as follows:

- Security assured thus the wealthy business community had an opportunity to exhibit their opulent life styles.
- Allocation of residential plots allowing for mix land use thus residential and work place.
- Financial assistance for these craftsmen to build their houses by providing for soft loans and easy installments spread over a larger period of time etc.
• Assurance from the king to facilitate the products to be sold either in the local market or to export them to Agra, Delhi, or outside the country via sea through Surat etc. Alternative road routes guarded for seamless export of products.

6.2 Contextual Urban design approach: Sustainable framework for Jaipur

<table>
<thead>
<tr>
<th>Indicators and sub-indicators</th>
<th>KEY CONTEXTUAL DESIGN APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental:</td>
<td></td>
</tr>
<tr>
<td>Water:</td>
<td>Locally available natural stream was tapped for water and manmade lakes developed standing till date; depicting knowledge of rainwater harvesting.</td>
</tr>
<tr>
<td>Waste:</td>
<td>The water supply initially was collected manually and now individual water supply through taps by municipal authorities.</td>
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<tr>
<td></td>
<td>As water was a limitation since the beginning the lifestyles were such that optimum usage of water was culturally driven and till date the consumption is 135-160 lpcd, much lower than the Bureau of Indian standards of 200 lpcd.</td>
</tr>
<tr>
<td></td>
<td>o the natural topography of land to drained rain water to the man made lakes.</td>
</tr>
<tr>
<td>Physical:</td>
<td>Orientation of streets such that the sun movement addressed for thermal comfort in narrow streets, as walking was the main system of circulation. Wherever the orientation not suitable then covered corridors were provided</td>
</tr>
<tr>
<td>Land</td>
<td>Interestingly the roof of these covered corridors proved to the open space available for public when processions were held be it religious or political few continuing till date.</td>
</tr>
<tr>
<td>Transportation</td>
<td>Mixed land use was typical with retail at the ground floor and residences at the upper floors; thus no travel to work or limited.</td>
</tr>
<tr>
<td>Architectural Heritage</td>
<td>The hierarchy of streets defined the activities in the streets from primary where commercial was predominant to the tertiary where spill over of residential activities was customary.</td>
</tr>
<tr>
<td>Socio-Economic Composition</td>
<td>As security was a concern when built the site selected is surrounded by Aravalli’s ranges that form a visual backdrop for the city till date.</td>
</tr>
<tr>
<td></td>
<td>Passive system solutions for thermal comfort, daylight and wind movement are typically inherent in traditionally planned built morphology &amp; continuing.</td>
</tr>
<tr>
<td></td>
<td>Use of red sand stone in lime evolved an architectural style that is inherent to the city with main streets retained till date for the image of the city.</td>
</tr>
<tr>
<td></td>
<td>Hindu base with balance of Brahmins, Business community, craftsmen, i.e. blue potters from Bengal, block printers from Sanganer, brassware workers from Mirzapur, inlay workers from Agra, lacquer workers from Jodhpur, etc. ( unique case as the entire population had migrated from near and far as well)</td>
</tr>
<tr>
<td></td>
<td>Unstable political situation assured the wealthy traders of security, an opportunity to live in a lavish style, facilitated with incentives.</td>
</tr>
<tr>
<td></td>
<td>Acknowledgement of King’s faith in religion and the related practices, which became the norm for the local people that with time became an integral part of the local culture.</td>
</tr>
</tbody>
</table>
6.3 Continuity of Contextual Urban design approach: Sustainable framework

The city of Jaipur has responded to growth and displayed resilience to changes from political, social, economic, cultural, technology and local events i.e. floods, riots, and others. All indicators are reflected in the built environment- physical dimension as follows:

- Impact of Urbanisation and Re-densification: The city has grown from a density from sixty to now about three hundreds persons per acre. It has got stabilised such as city has expanded outside the city walls but the walled city continues to be the nuclei.
- The built morphology of low-rise high density maximum as ground plus three.
- Visual backdrop of Aravalli hills intact till date with all the existing streets as designed.
- With re-densification the infrastructure facilities layered on the city each layer with each one legible demonstrating the adaptability to governance, social, economic, technology.
- Ownership & real estate: the real estate prices are highest and usually not even available as the local population continues their strong hold. Habitually most of the properties have multiple owners thus a deterrent for resale, a limitation by default but in favor of the archetypal built environ.
- Mixed land use and Hierarchy of streets: The mixed land use is continuing and has spilled over to the secondary and occasionally even in tertiary streets: a strong display flexibility of the space utilisation.
- Although the main streets housed retail and commercial but with time few of the crafts are highest exported products of the country thus to address the global markets they are concentrated typically in one of the streets. Such a paradigm shift demonstrates the resilience of socio-economic setup.
- Open spaces: It is remarkable to note that the open spaces designed are continuing till date. Except for the palace square that has large open space for which the local authorities have plans to develop for cultural tourism. The water edge of the manmade lakes too is an opportunity for the people of the city and has been designed. (CDP: JNNURM: 2006)

![Relative Sustainability of the City of Jaipur 1728-2007](image)

Fig 2 Relative sustainability for the city of Jaipur (source: author)
Master plan 2011 planning statistics as: walled city workforce 51841[46.42%] share of population of the walled city: 32.67%; major contributor to the city’s economy, nearly 30% people inherited family trade nearly 47% walk to the place of work.

The circulation within the city continues to be pedestrian with cycle rickshaws that are manually driven thus providing job to the locals and eco-friendly as well.

The case example of Jaipur clearly demonstrates the strength of a contextual urban design approach. The learning’s are many form macro to micro and this wisdom of knowledge if not carried forward may be a permanent loss with time.

![Fig 3 Sustainability polygon for the city of Jaipur (source: author)](image)

7.0 Conclusions

The paper focused on significant issue of the role of urban design approaches by offering a framework of sustainability indicators arrived at for a specific context within the literature. The paper opens up with understanding urban design and various approaches that evolved with time within the realm of urbanization and development. With this backdrop understanding and criticism of ‘Contextualism’ in the larger debate on sustainability at global level. Through the literature one has considered specific aspects to different approaches that have been reflected. Narrowing it down to global south wherein context has been instrumental in shaping up of urban developments that have sustained and have thrived enjoying their respective identity an issue largely diluted with global architectural vocabulary. Each of these contextual urban developments display a plethora of solutions that are time tested and may be acknowledged as best practice for the respective region. The intention is to be rational and judicious about accepting and acknowledge the sustainable practices around us. In the name of progress and development one often looks upon going back to the origin or history or traditional but for any development initiative only a rational approach addressing all aspects with varying weightage thus a reflection of context is the way forward. This paper puts forward an argument to reaffirm the contextual urban design approach to be integral for the world if it needs to be sustainable.
Having shared the knowledge of various approaches, methodologies and times the view is argued, analysed and drafted a contextual urban design framework. The rationale of methodology; the UN Framework of sustainability indicators is selected to as by virtue of its universal acceptance. This is overlaid with the traditional/historical/regional/local connotations. The exercise conducted is fundamental to the resultant framework. By applying the knowledge of contextualism to case study for the city of Jaipur and tested.

The objective of the paper was to establish the significance of contextual urban design approach that is sustainable and relevant even today. The same has been proven with a case study of living traditional city of Jaipur. The importance of such a case example gets reinforced, as there is large number of historic cities in Asia. The information of the case study shared in this paper is a part of the doctorate work including diagrams fig2 and fig3 (Sharma.A.K; 2012)

The paper analytically maps a set of key sustainability indicators of contextual urban design and for the success it may be considered for other case examples to further answer the said research. The suggested framework paves the path for more critical analysis. The shared body of knowledge is essentially to from a backdrop and to provide a fundamental vocabulary for communication between professionals and a departure point for further research. The study hopes to reduce the gap by providing a methodology that should be extended to multiple other cities and different urban configurations and contexts to have a sustainable world.

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Bahrainy, H; Bakhtiar, A. 2016 – TOWARDS AN INTEGRATIVE THEORY OF URBAN DESIGN ISBN : 978-3-319-32663-4 http://www.springer.com/978-3-319-32663-4

Building Urban Resilience in Egypt, The Case Study of Nuweiba in South Sinai

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Abstract: Cities all over the world are suffering from various chronic and severe problems which are related to fragile economic development, poor infrastructure, environmental degradation, climate change, human capital as well as social segregation and polarisation. Most of these complex problems are interwoven to the city’s urban fabric that later cause non-equilibrium to the urban systems. Accordingly, a robust governance system is needed to untangle the complexity of all those challenges then effectively manage the city’s urban systems. This paper aims to fill the theoretical and practical gap of urban resilience which is known for its complexity and multidisciplinary. A case study of Nuweiba in South Sinai, Egypt, is selected to come out with a city resilience framework. This framework aims to regulate the relationship between the local community and local authorities in order to move towards a more resilient state. The study in this paper is divided into three parts: The first is understanding the concept of resilience as well as the context of the chosen city, the second is analysing the dynamics and the driving forces which led to changes in the city seven capitals, while the third part is concerned with the assessment of responses towards the changes in city capitals to spiral it up for development.

Keywords: urban resilience, integrated planning, resilient cities, integrated sustainable development

Introduction

All over the globe, acute shocks smash many urban areas with floods, seismic forces, epidemic diseases, terrorism, more hazards and conflicts. Also, chronic stresses such as land ownership, unemployment, depletion of resources, absence of public transportation, lack of services and infrastructure, weaken the city urban fabric. Cities are challenged with a wide range of disruption due to either natural or man-made pressures. They are cascaded with the burdens of economic decline, social breakdown or system collapse. Traditionally, urban risk management is concerned with understanding the impact of a specific risk and then taking actions to mitigate it. Nevertheless, the diversity of increasing risks, the complexity of cities’ systems, globalisation and rapid urbanisation, have put building urban resilience into the top of the critical agenda.

Cities are systems of systems which are flexible to be organised so that they can protect individuals, communities, institutions and businesses in case of turbulent change. To enable resilience in city systems and prevent breakdown, all systems should have those 7 qualities: inclusiveness, integration, reflectiveness, resourcefulness, robustness, redundancy, and flexibility to keep and achieve resilient cities (The Rockefeller Foundation and ARUP, 2014).

This paper is a part of a comprehensive study for a M.Sc. thesis which focused on community resilience for developing an urban city. The main tools used for data collection phase are: field survey, interviews, focus group discussions with more than 40 community members in two weeks. The result of this paper comes out with a framework for resilience.
Resilience Definitions

Resilience is a general vague term that has many definitions. In the mid-17th century, resilience as a word first appeared after being originated from the Latin word "resalire" which means to bounce back. Resilience is also defined as the capacity to deal with unexpected risk after learning manifestly how to spring back (Wildavsky, 1988). And, it is also about managing the existing resources and skills to use them when needed during severe conditions (Comfort, 1999). Scientists first used the term of resilience in material science, to describe the changes of the resisting material during its exposure to external impact shocks (Davoudi et al., 2012). Then, it entered the field of ecology and environment which considered the resiliency of a system as the amount of absorbed disturbance to keep the structure of urban system stable by minimal changes in some variables and processes that control behaviour (Holling, 1996). Other hybrid definitions which are being used in the interdisciplinary field, were emerged after combining between various fields (Folke et al., 2010). For instance: socio ecological resilience appeared when merging between social science, Engineering and ecology.

Urban Resilience in Theories

Urban resilience is a valuable concept that gained popularity in multidisciplinary field. It is defined in theories by many scholars as the capacity of cities to function or keep their equilibrium when they are affected by sudden shocks or frequent stresses, so that the vulnerable community can survive. Meanwhile, urban resilience is still unclear like its broader concept, this vagueness hindered the process of measuring and operationalising it. Accordingly, a common definition is needed to be agreed upon to fasten its application on cities. Meerow et al. (2016) has recently defined urban resilience as an urban system which consists of socio-ecological and socio-technical constituents. They are spatially interconnected to maintain their functions or to transform rapidly when a change occurred. To articulate a measurable urban resilience, accessible data should be available to feed the urban planning practices and investment patterns for vulnerable communities. So, the resilience of a city can be measured by both the resiliency of physical systems and the community's capacity that can withstand, manage and survive disastrous events (Godschalk, 2003).

Building resilient urban system requires various levels of incremental alterations. When thinking to apply resilience as a concept on urban areas, it is important to consider regional assets that may be outside the physical boundaries of the city but play an influential role in their functioning such as services and natural assets. Also, territorial development and planning is an effective way to enable building resilience for sustainable cities (Meerow et al., 2016). Therefore, using a whole systems’ approach is crucial for resisting changes or for radically transform to a new desired trajectory to understand and build resilience for urban systems and future inhabitants.

Urban Resilience in Practice

Many approaches, frameworks and tools are adopted to analyse, assess and operationalise urban resilience. The conventional approaches are concerned with reducing the risk to tangible capitals, for instance: physical capital like buildings, utilities and infrastructure in addition to environmental capital to mitigate the risk of climate change. However, there are other approaches that include the intangible capitals, such as: social, cultural and institutional capitals which play a critical role in making cities and communities bounce-back rapidly in the
aftershock. Moreover, various tools and frameworks depend on either both of qualitative and quantitative indicators or one of them. To enable assessing and operationalising urban resilience, certain questioned must be addressed, for instance who determines what resilience for whom? Why? Where? And when? (Meerow et al., 2016).

The Rockefeller Foundation and ARUP, (2014) developed a comprehensive tool for measuring, understanding and assessing city resilience. However, this tool lacks the specific steps of operationalization. The city resilience index tool gives clear understanding about the city's urban systems and is used either by decision makers or communities to develop resilience mechanisms or prolonged strategies. According to the Rockefeller Foundation and ARUP, resilient urban systems should be reflective with mechanisms to continuously evolve the response to an uncertain future based on new emerging evidence. So, it is certainly crucial for people and institutions to learn from the past experiences to inform decision makers and propose innovative ideas. Robust, with well-conceived constructed and managed physical assets so that they can withstand the impact of shocks without failure. Redundant, with spare capacity that is intentional and cost-effective such that systems can accommodate disruption, extreme pressures and surges in demand. Resourceful, such that people and systems can rapidly find different ways to achieve their goals or meet their needs at the time of shocks. Flexible, meaning they can change, evolve and adapt in response to circumstances after relooking to the indigenous knowledge and traditional practices in a new way. Inclusive, by emphasising on the need for broad consultation and engagement with the poor and most vulnerable groups to determine the city's identity besides sharing their goals for future visions. Integrated, by ensuring alignment between city systems promoting consistency in decision making and making investments mutually supportive to a common outcome.

Nuweiba Context, Community and Capitals

Nuweiba is a developing city on the Gulf of Aqaba in south Sinai governorate, Egypt. It is characterized by its pristine nature and the authentic Bedouin culture. It is located 465 km from Cairo, 150 km from Sharm el sheikh and only 70 km south of the Egyptian-eastern border. The area of Nuweiba is around 7000 km2 which represents 22.3 % of the governorate area as in figure1. It includes only 8 residential agglomerations with greater Bedouins majority (SDA, 2018). In primary life, Nuweiba used to be a rudimentary underdeveloped area for thousands of years until the Israeli occupation of Sinai in 1967 and transformed the city into an urban village. After the departure of the Israeli forces, Nuweiba started to grow rapidly. Nuweiba port was built in 1985 to transport goods and people to Jordan and the Saudi Arabia, besides dozens of worldwide known hotels and resorts have been established there. These developments formed the city's economic and touristic character.
Many years ago, Nuweiba peoples were only Bedouin from two tribes which are Tarabin and Muzeina. They used to be nomads and semi-nomads who depend on pastoralism as a main source of their livelihood. Yet, they settled down on their traditional territories in Nuweiba during certain sessions to collect dates and do fishing. Although the Bedouins' life was very primitive at that time, they used to master managing it due to their high attachment to the natural environment. Then, Bedouins started to live in houses on the coast of Nuweiba to work in tourism and work as farmers in the three introduced farms during the occupation period. Since then, the coping actors left their traditional goat hair house and tents to learn new skills so that they can afford their living. Nowadays, Nuweiba residents are not only the indigenous Bedouins but also Egyptian migrants who came from northern and southern Egypt, or foreign migrants who came from all over the world to live and invest in this critical location. Are urban systems and city capitals resilient enough to meet the needs of this social mix? or building urban resilience is crucial at the moment?

According to (Flora et al., 2005), there are seven capitals that should be considered to build resilience of city's urban systems as shown in figure 2. Those capitals are the natural capital - physical- human- economic- institutional- social and cultural capital. The seven capitals are the essential assets that any community living in urban areas should have, to reach three main goals; social equity, vibrant economic growth and ecosystem preservation. Those seven capitals are interlinked and help to holistically detect any changes in the urban system. Thus, the urban system in each city require all or more than one capital for its stabilisation.
The Challenges of Urban Resilience in Nuweiba, Egypt

The city was exposed to multiple shocks and stresses which act as driving forces of Nuweiba urban transformation in the last two decades. Yet, it showed diverse levels of resilience in its capitals. From the stresses that are frequently happening in Nuweiba, the environmental routine hazard of flash flood and landslides that cause losses in the physical, economic and human capitals. Also, the long year of occupation until 1982, was in the beginning a sudden shock then it turned into an unrelieved stress which critically affected both the institutional and human capital. The local government lost the sovereignty over Sinai for almost a decade which resulted in major degradations on the social and cultural level, besides natural resources were exploited, not by force or oppressions but after negotiations using the radical inferiority and superiority complex concept.

Recently, globalization has become one of the most hectic drivers behind the newly transforming cities like Nuweiba. Due to globalization, the city witnessed a significant economic growth and development since late 80s until the revolution in 2011, however, this growth was mainly built on tourism industry. The undiversified economic base and the increased foreign as well as domestic investment in tourism changed the dynamics of nomadic Bedouin community and encouraged them to be modernised. Also, many migrants from upper Egypt and the Nile delta moved to Nuweiba seeking better opportunities.
Accordingly, the identity of the place and its indigenous community was altered, and virginity of nature was ruined by the concrete mass constructions. Moreover, the absence of decentralized governance system and low level of integration of this peripheral society, make the city more prone to the threats of globalization and not its advantages. However, Good governance could have utilised the opportunities of globalization to build resilient urban system and leverage community resilience to adapt to the upcoming change.

Nuweiba community has recovered from many challenges either by adaptation, mitigation or avoidance. The community gradually moved from being adaptive managers, to coping actors then to powerless spectators, as explained earlier, due to stresses on one or more capital. When comparing the changes in the seven capitals before 1960s, during the underdevelopment life and throughout the Israeli occupation period, it’s clear in figure 3 that there was a drop down in the political or institutional capital since the indigenous Bedouins were no more controlling their territories. However, the local economy was revived due to the availability of many job opportunities in different sectors. While, the comparison of capitals' change after Sinai liberation period and after the Arab spring revolution, showed that the undiversified economic base which mainly depended on tourism after liberation in 1982 led to the regression in the economic capital due to the sudden failure of tourism after the multiple terrorism attack in Sinai and the area starting from the ongoing 21st century. Yet, more efforts were directed towards preserving the natural environment either in the sea or up the mountains after the 25th revolution, as shown in figure 4.

![Figure 3. The changes in the seven capitals during the underdevelopment life and the Israeli occupation period, Source: author based on conducted field surveys and interviews](image-url)
There are many interventions in response to the faced challenges either from the local Bedouin community, migrants or investors to strengthen the 7 capitals and to mitigate the impacts of past and current challenges. In figure 5, it is shown that migrants' responses are more directed towards promoting for Bedouin culture, making profit and encouraging people to learn new skills. Unlike the migrant and investors, the locals were more concerned with the social capital to keep the ancestral ties strong and the political capital to reinforce the self-governance so that they can participate in decision making. The following are two examples of community responses, the first is a response from local Bedouin tribes and the second is a response from one of the investors who migrated from Cairo after Sinai liberation.

**Sinai Trail**

Sinai trail is a cooperative of three Bedouin tribes who decided to revive part of the traditional trial to saint Catherine monastery after tourism declination and the limited income sources. The three tribes designed the first longest hike in Egypt in which each tribe manage and responsible of securing the trail on its traditional territory. The trail extended for 200 km from the Gulf of Aqaba to the summit of saint Catherine (Sinaitrail, 2017). Cooperative members always develop themselves and the activities during the trail. They are trained to be guides for tourist, they learn languages and they also took first aid courses to medicate hikers in case of injury. Sinai trail became a well-known trail among Egyptians and foreigners. It succeeded to recover and retrieve indigenous knowledge, traditional skills, strengthen social ties between different tribes, encourage tourism development and culture exchange.

**Habiba Organisation**

Habiba organisation was initiated in Sinai in 1994 based on love and passion to people and Sinai land. Habiba started strong relations with the locals and rapidly integrated within...
Nuweiba community. First, a beach lodge was built that is based on tourism as a main activity. However, after sudden terrorism attacks and tourism declination, Habiba opened an organic farm in 2007 to ensure food security and alternative economic source. The organisation has called for sustainable voluntourism as a new type of tourism in the area, in addition to encouraging tourists and volunteers to interact with the local Bedouin community, learn organic farming principals, food security and environmental protection. Moreover, a learning centre that offers educational and entertainment services for Bedouin community, was recently opened. It helps children to interact with each other, explore the environment, effectively manage resources, learn and develop their skills (Habiba, 2018). Habiba’s model is a very interesting and successful model in such a developing city like Nuweiba.

City Resilience Framework

Since, city resilience is defined by the ability of its system such as governance, social, cultural, physical, human, economic and natural systems to learn from the past experiences and face hazards to be ready with plans so that it can preserve and restore structures and functions. Building urban resilience in Nuweiba is crucial. It requires for instance clear environmental protection methods through community-based organisations and the Egyptian Environmental Affairs Agency to strengthen the natural capital. While, it is important to encourage the move of qualified labours and experienced professionals to the city to enhance the human capital. The following city resilience model is introduced to define domains for each capital as shown in figure 6. The city resilience framework enables assessing each capital after intersecting each of them with the 7 qualities, so that definite decisions can be taken to help in building city capitals.
### City Resilience Framework with Identified Domains and Actions for Assessing and Operationalising Urban Resilience

<table>
<thead>
<tr>
<th>7 Capitals</th>
<th>7 Resilience Qualities</th>
<th>Urgent Needed Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Biodiversity</td>
<td></td>
<td>It is highly recommended to encourage the establishment of CBOs for natural environment preservation.</td>
</tr>
<tr>
<td>2. Food</td>
<td></td>
<td></td>
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<tr>
<td>3. Local landscape</td>
<td></td>
<td></td>
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<tr>
<td>4. Natural resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Natural attractions</td>
<td></td>
<td></td>
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<tr>
<td>6. Fresh water availability</td>
<td></td>
<td></td>
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<tr>
<td>7. Building materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Social networks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Communication and networking capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Local leadership</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Adaptive strategies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Civic participation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Community based organizations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Social structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Human</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Educational level</td>
<td></td>
<td>It’s recommended to encourage the move of new professionals and qualified labourers to the developing city.</td>
</tr>
<tr>
<td>2. Age</td>
<td></td>
<td>In addition to organizing self-help groups to solve problems via trusted legitimized leaders.</td>
</tr>
<tr>
<td>3. Demographic data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Ideologies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Experience of collaboration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Motivation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Local Knowledge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Volunteerism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Creative population</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cultural</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Migration patterns</td>
<td></td>
<td>It’s also recommended to revitalize culture by organizing traditional festivals which encourage local as well as foreign tourists to know more about Nuweiba community.</td>
</tr>
<tr>
<td>2. Traditional activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Skills and training</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Ethical standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Traditional knowledge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Cohesion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Identity of the city</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Language competency</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Unemployed population</td>
<td></td>
<td>It’s recommended to support local business specially SMEs and to have a diversified economic base build on local resources and traditional skills.</td>
</tr>
<tr>
<td>2. Business size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Diverse economic base</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Secured livelihood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Economic transition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Access to fund</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Marketing channels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. SMEs and businesses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Informal economy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Income and equality</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Institutional</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Access to resources</td>
<td></td>
<td>It’s recommended to encourage community empowerment programs. Strengthen leaders’ connections with the state and local government. Lessen the complications of land and shelter legalization mechanisms.</td>
</tr>
<tr>
<td>2. Power relations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Land ownership</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Regulation and standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Mitigation plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Recovery plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Municipal services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Community participation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Governance system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Safety and security</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Labor policy</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Housing typology</td>
<td></td>
<td>- Develop a traditional theme for building construction in areas like Nuweiba.</td>
</tr>
<tr>
<td>2. Energy supply</td>
<td></td>
<td>- Use of local materials from stones, reed and clay in building constructions</td>
</tr>
<tr>
<td>3. Home age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Medical capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Educational capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Infrastructure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Roads and transportation access</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Informal areas</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. City resilience framework with identified domains and actions for assessing and operationalising urban resilience. Source: Author
Resilience Methodological Diagram

Empowering Nuweiba community can help in building urban resilience since Nuweiba people are from the key actors of development. They can plan and act to eliminate or at least mitigate the vulnerability of urban systems to adverse situations (proactive activities) as well as to plan and act to reduce the opposing effects of possible perturbations (reactive activities), while the local political will can support community resilience by backing the community with alternative plans and long-term national visions to ensure active positive adaptation of urban systems to the changing development conditions. Developing urban structures which are appropriate from the view point of resilience requires that local authorities (including city residents and other stakeholders that can be included in a city’s regulatory system) to be aware of the expected risks, prepare their urban systems for such risks and develop skills of a rapid and efficient response when such risks occur.

Thus, building local resilience can be easily implemented through influencing the community’s ability to successfully respond to changes in each city capital. A methodological diagram was developed as shown in figure 7, in order to build as well as operationalise resilience pre- hazardous event, during the event and after the event, on the local and institutional level to take collective actions.

Pre-Event
Before any anticipated or unanticipated risk, it is really crucial to build a database of previous events. On the local level, the community and its local organisations should recall the past and current challenges, study the spontaneous responses and actions. Then, define the active stakeholders, so that resilience estimations models can be documented, and resilience domains can be easily defined. However, on the institutional level, the city council should predict the upcoming challenges, boost people awareness of the coming risk and estimate community responses. Additionally, risk and mitigation plans should have been prepared and guidance and support to the community should be provided to ensure the city’s stabilisation.

During the Event
It is all about precise collective actions at the right time. On the one hand, all city assets should be well managed to take definite actions for risk mitigation. If those actions are not suitable, changes in urban systems should be considered or support from definite stakeholders might be required. On the other hand, city officials should encourage innovations, execute advanced actions and be ready with emergency plans.

Post Event
It is important to look back to the event, document actions and study its consequences. Accordingly, effective stakeholders should be reidentified, update the database of events and resilience domains for better performance criteria. Loss evaluation, system and self-evaluation should be done on local as well as institutional level. Simultaneously, recovery plans which offer hope and motivation to the community, must be provided by the city officials in all systems. Then, it is required to jointly develop long term national security plans to guarantee prolonged city resilience.
Conclusion

In conclusion, this study provided some insights on resilience concept and its applications on cities and urban communities. It is important to start from looking back to the history with all its challenges and events. Then, assessing the resources of the status quo to build urban resilience. A framework for understanding and assessing the city and community capitals is proposed to be ready for applying resilience which needs interdisciplinary studies for successful planning and effective development processes.
References


Chapter Six: Thermal comfort, health and wellbeing
Thermal comfort conditions and air quality in educational buildings in Cyprus during the heating period: the impact of natural ventilation

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Abstract: This paper aims to investigate the indoor comfort conditions in a typical classroom of a secondary school in Cyprus and explore the impact of natural ventilation on both thermal comfort and air quality. Natural ventilation is a significant parameter in the design of school premises as it affects human comfort conditions and thus students’ health, learning ability and performance. Within the frame of the present study indoor and outdoor environmental conditions were seasonally monitored. Various ventilation strategies and window opening patterns were examined in order to identify the best option to exploit natural ventilation as a means to achieve optimum air quality, especially during wintertime. The in-situ measurements of temperature and relative humidity were analysed in correlation with CO₂ levels. Data was collected during both occupied and unoccupied hours. The measurements indicate values that often exceed the limits defined by standards. Moreover, the study shows that selected ventilation patterns, and window opening patterns, allow the improvement of air quality with minimum heat losses in wintertime. Conclusions present potential improvements in achieving better air quality and thermal comfort conditions. Educational buildings in Cyprus may utilize the proposed improvements, as well as other similar buildings in southern Europe, with climatic conditions and building typologies in educational architecture as those described in the Cypriot setting.

Keywords: thermal comfort, air quality, natural ventilation, educational buildings, Southern Europe

Introduction

Various studies assessing the impact of the classroom environment on students’ and staff’s health and performance have recently been published (Buka et al. 2006; Bako-Biro et al. 2012; Wargocki and Wyon 2013). It seems clear that the amount of time spent in school premises affects school indoor environmental quality (IEQ) which, in turn, influences students’ health, attitude and performance. Children are more sensitive to the unpropitious effect of indoor pollutants caused by poor air quality in schools (W.H.O, 2005). The operation and maintenance of educational buildings often suffers from a lack of proper care leading to persistence of environmental problems in educational buildings. Consequently, there arises the need for retrofitting of schools in order to ensure sufficient conditions for users to fulfil their activities.

Providing fresh air from the external environment, through proper and adequate ventilation, rarefies the concentration of internal pollutants and achieves amelioration of indoor air quality (IAQ). It has moreover, been established that fresh air movement in the classroom increases the productivity of students (Turanjanin et al. 2014). Apart from outdoor air pollutants, temperature is also important for students’ performance (Haverinen-Shaughnessy et al. 2015). High thermal comfort resulting from better living standards raises energy demands in cases when the building is unable to maintain adequate indoor thermal conditions. As of the above, it becomes evident that thermal comfort in educational buildings is an essential design parameter (Taleghani et al. 2014).

Within this framework, the current research aims to evaluate the indoor air quality and thermal comfort conditions in a typical secondary school in Cyprus and explore the impact of natural ventilation on both thermal comfort and air quality by monitoring four classrooms of the school. Various ventilation strategies and window opening patterns were examined in
order to identify the best option to exploit natural ventilation as a means to achieve optimum air quality, especially during wintertime. The data was recorded for both weekdays and weekend. Both CO₂ concentration and comfort variables in the building were correlated with the standards. Proposed improvements will increase environmental awareness as schools are among the most promising public building types to act as lighthouse projects. Pupils can experience the visible improvements to the building envelope of classrooms and they can learn how to support energy savings and indoor air quality by responsible user behaviour. It is not uncommon for educational buildings in other countries of southern Europe that share similar climatic conditions with Cyprus to have classroom arrangements of a similar linear disposition connected with semi-open corridors. The results of the present study could thus be successfully employed beyond the geographical limits of Cyprus.

Research Background

Many research studies highlight the significance of thermal comfort and the role of natural ventilation in the promotion of indoor thermal satisfaction. In most educational buildings, natural ventilation is the only means of fresh air inside the building, so it is more difficult to control and maintain IAQ in these buildings (Turunen et al. 2014). Moreover, due to high occupation density and excessive internal gains in classrooms, ventilation increases which makes IAQ and thermal comfort an even more essential parameter (Theodosiou and Ordompozanis, 2008). Daisey et al. (2003) and Sundell et al. (2011) reviewed studies conducted in schools and concluded that poor classroom ventilation is a cause of health symptoms. Although many studies, included in this review, monitored various environmental parameters in educational buildings, much fewer investigated the association with school occupant’s health and only two mentioned the interrelation between ventilation rates or CO₂ and health effects. Recent studies have also revealed the relationship between inadequate ventilation and learning ability (Haverinen-Shaughnessy et al. 2015; Bako-Biro et al. 2012).

Frontczak and Wargocki (2011) studied the impact of different parameters on human comfort concluding that thermal comfort is the most significant factor in indoor environmental quality assessment and that occupants of naturally ventilated buildings engage in a more adaptive behaviour. Wargocki and Wyon (2013) carried out a study in 5 primary schools and concluded that the performance of students deteriorates by 30% in conditions of high CO₂ concentration and high temperatures. Natural ventilation is not only favourable for thermal comfort but it additionally provides indoor air quality. Coley and Beisteiner (2002) monitored UK primary schools and concluded that opening windows between classes can reduce CO₂ levels and other contaminants to acceptable limits.

Research Methodology

Description of case study area and climatic conditions

For the purposes of the current study, a typical secondary school, located in the urban area of Nicosia (latitude 35°10′ N and longitude 33°21′ E), Cyprus, was selected for an in–depth investigation. The island has a typical Mediterranean climate featuring hot-dry summers and cold-wet winters. According to the Department of Meteorology (2018), in January and February - the coldest months of the year - mean temperatures reach 10.6°C with mean low temperature 5.2°C. In July and August - the hottest months of the year - mean temperatures reach 29.7°C while mean high temperatures reach 37.2°C. Daily temperature fluctuations range from 8 to 10°C during the cold months while they reach 16°C during the hot months. The annual mean precipitation is 342.2mm.
Description of case study building

The school building is a challenging space in terms of comfort levels as students spend around one third of their entire day in these premises. The Technical Services of the Cyprus Ministry of Education and Culture are responsible for the design and structure of all schools in Cyprus; this ensures uniformity in terms of typology, morphology and construction. Therefore, considerable similarities, substantial standardization of building components and construction methods is found in the architectural design of schools (Fig. 1) (Michael, 2012). Classrooms have a slightly rectangular shape with dimensions of approximately 7.00×8.00×3.20m (W×L×H) (Fig. 2). The linear disposition of classrooms enables the placement of openings along the two long sides of the space.

A representative case study with typical characteristics in terms of typology, construction, as well as integration of environmental design principles, was selected in order to assess the air quality and thermal comfort of the typical classroom of educational buildings in Cyprus. This is the secondary school in Nicosia; namely, Archbishop Makarios III Secondary School.

Figure 1. (a) Educational buildings of secondary education are characterized by uniformity in terms of typology, morphology and construction, (b) Linear disposition of classrooms (c) internal view.

Figure 2. Plan layout of a typical classroom of secondary schools in Cyprus where the openings A to N, and the locations of the installed recording equipment, for indoor and outdoor environmental conditions are indicated.

The analysis of different ventilation strategies is based on four typical classrooms of general education, on the first floor, in south orientation. Openings provide natural daylighting and heat gains along the two long sides of the space (i.e. extensive windows in the interior side and clerestories on the exterior). The openings to floor ratio is 35%. It is worth
noting that no building or plant elements shade the openings. More specifically, in each classroom, there are six glazed windows at the south side, i.e. C-H, a fixed glazed window at the south side, i.e. B, a semi-glazed door at the south side, i.e. A, four fixed clerestories at the north side, i.e. I, K, L, N, and two openable clerestories, i.e. J and M (Fig. 2). The classrooms are connected with semi-open corridors, 2m wide, which provide solar protection to all windows. No external shading device is available on the clerestories in the other long side of the classroom. Students use internal black-out curtains to eliminate solar radiation; however, at the time of the experiment, they were kept open. The classroom has an occupancy profile of 23-25 students on weekdays from 07:30 to 13:35 with 3 small breaks; however, in some cases, students are moved during the day to other laboratory, or fitness, classes to engage in other activities. The construction details are summarized in Table 1. Airtightness is a significant factor of the energy efficiency and IAQ of a building. In order to determine classroom airtightness, an experimental procedure took place using the fan pressurization method (ISO 9972:2015). The test determines the air change rate at a pressure difference of 50 Pa \( (n_{50}) \). The accuracy of the pressure channels of the blower door is +/- 1% of reading, or 2 times the resolution, whichever is greater. A test was performed in one classroom (C3). The experiment was performed for the “in use scenario” where nothing was sealed. This includes leakage from neighbouring classrooms that measures internal building leakage corresponding to typical use conditions (method A of ISO 9972:2015). The results show 9.4 air change rate per hour (ach) at a pressure difference of 50 Pa.

### Table 1. Construction characteristics and material of a typical school

<table>
<thead>
<tr>
<th>Building Elements</th>
<th>Construction Detail</th>
<th>U-Value ( (W/m^2K) )</th>
<th>Effective Thermal Capacity ( (KJ/m^2K) )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Wall</strong></td>
<td>200mm single layer of brick and three layers of plaster (20-25mm)</td>
<td>1.389</td>
<td>120</td>
</tr>
<tr>
<td><strong>Internal Wall</strong></td>
<td>100mm single layer of brick and three layers of plaster (20-25mm)</td>
<td>1.235</td>
<td>120</td>
</tr>
<tr>
<td><strong>Roof</strong></td>
<td>Concrete slab and asphalt layer of 5mm</td>
<td>3.239</td>
<td>240</td>
</tr>
<tr>
<td><strong>Ground Floor</strong></td>
<td>Concrete slab and tiles</td>
<td>1.6</td>
<td>232</td>
</tr>
<tr>
<td><strong>Window</strong></td>
<td>6mm single glazed and 60mm aluminum frame algebra ratio 15%</td>
<td>6</td>
<td>g-value 0.82</td>
</tr>
<tr>
<td><strong>Airtightness</strong></td>
<td></td>
<td>9.4 ach @50 Pa</td>
<td></td>
</tr>
</tbody>
</table>

### Field study methodology

A field study was carried out for the investigation of air quality, thermal comfort and the impact of natural ventilation on the above parameters in educational buildings, during the cold winter period, specifically from 10\(^{th}\) February to 16\(^{th}\) February 2018 and during the end of the winter period and beginning of spring, i.e. 3\(^{rd}\) March to 9\(^{th}\) March 2018. The data was selected during both occupied and unoccupied period. The pattern of occupancy for each classroom varies during the week and day. It is noted that some classrooms were also used in the afternoon (14:45-18:00) with a smaller number of occupants i.e. 6-8 in each classroom. Worth noting is also the fact that technical heating during winter is available through a central heating system between 7:00-10:00 and 14:45-17:45.

The intervals of the recordings of indoor environmental parameters were set at five minutes. The UX100-003 HOBO data logger was placed to record classroom temperature and relative humidity with an accuracy of ±0.21°C from 0°C to 50°C and ±3.5% from 25% to 85% including hysteresis at 25°C respectively. For the CO\(_2\) concentration, Extech CO210 data logger.
was used with measurement range from 0 to 9999 ppm. The sensors were placed at a height of 1.1 m above floor level, which was approximately the mean height of the window openings, i.e., B-H and the height level of the head of sitting students (EN ISO 7726:2001). The equipment was placed in selected locations, as shown in Fig. 2. The devices could not be placed in the middle of the room as they would obstruct the normal class schedule. At the same time, an outdoor weather station was installed at the roof of the building at a height of 10m above street level, i.e. approximately 4m above the average height of buildings located in the surrounding area. More specifically, a Vantage Pro 2 Plus weather station, with an accuracy of ±0.3°C from -40 to 60°C, was used for outdoor air temperature, with measurements ranging from 1m/s to 809m/s for air velocity.

In this framework, various experimental ventilation strategies were investigated to determine the impact of ventilation on educational buildings and possible improvements. Table 2 summarizes the ventilation strategies under examination.

<p>| Table 2. Ventilation strategies and window opening patterns examined during the field study period |</p>
<table>
<thead>
<tr>
<th>Period of opened windows</th>
<th>Break time ventilation</th>
<th>Teaching period ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st break (20 mins)</td>
<td>2nd break (20 mins)</td>
</tr>
<tr>
<td>CASE 1 WEEK 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 1 C1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Case 2 C2</td>
<td>Single Sided 1/2</td>
<td>-</td>
</tr>
<tr>
<td>Case 3 C3</td>
<td>Single Sided 1/2</td>
<td>-</td>
</tr>
<tr>
<td>Case 4 C4</td>
<td>Single Sided 1/2</td>
<td>●</td>
</tr>
<tr>
<td>CASE 2 WEEK 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 5 C1</td>
<td>Single Sided 2/2</td>
<td>●</td>
</tr>
<tr>
<td>Case 6 C2</td>
<td>Cross ventilation</td>
<td>●</td>
</tr>
<tr>
<td>Case 7 C3</td>
<td>Single Sided 1/2</td>
<td>●</td>
</tr>
<tr>
<td>Case 8 C4</td>
<td>Single Sided 1/2+ door</td>
<td>●</td>
</tr>
</tbody>
</table>

The objective of the experiments was to achieve optimum air quality with the least adverse impact on thermal comfort. The experiment was conducted in two periods, following some observations made during the first period. Specifically, the different experimental ventilation strategies were examined during weekend, Monday and Tuesday (four consecutive days). In the first week, single-sided ventilation strategies were examined for different times of the day in four classrooms. The openings that remained open were C and F (that is, half of openable windows in a single side). In Case 4, windows opened during all break times (08:50-9.10h, 10:30-10.50h and 12.10-12.15h), in Case 3, windows opened in the last two breaks, in Case 2, windows opened during the last break only in midday. In Case 1, all the openings remained closed, i.e. no ventilation was monitored, in order to be used as reference scenario.

During the second week, attention was paid to different opening patterns of Case 4 (i.e. openings remained open during all break-times). In case 7, the same opening pattern was used as Case 4, i.e. openings C and F remained open during break-time. In Case 5, all openable windows of a single side remained opened (i.e. C, E, and G), and in Case 6, cross ventilation was achieved when openings C, F, J and M remained open during break-time. In Case 8, opening C and F remained open together with door A; however, door A also remained open during teaching periods in order to provide continuous fresh air.
**Data Analysis Methodology**

The CO\(_2\) concentration is analysed in correlation with the air temperature of both the internal and external environment in order to assess indoor air quality and thermal comfort, the contribution of each ventilation strategy to air quality and thermal comfort. According to the Representatives of European Heating and Ventilation Associations (REHVA), the acceptable limit for CO\(_2\) levels is 1500 ppm (d’ Ambrosio Alfano, 2010). The same limit is set by the authority of the public educational buildings in the United Kingdom (Building Bulletin BB101, 2006), and the same appears in the German and Swiss Standard (DIN 1946 1994, SIA 328/1 1992). According to the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) standards 62. 1-2016 (2010), the limiting value during the occupied period is 700 ppm above outdoor CO\(_2\) levels (300-500 ppm). According to the European Standard EN 13779 (2007), indoor air quality is achieved with less than 400ppm above outdoor levels, medium quality is achieved in the range between 400-600ppm, moderate quality from 600 to 1000 ppm and low quality above 1000 ppm. In this research, the CO\(_2\) concentration of 1500 ppm was set as an acceptable limit.

The Adaptive Comfort Standard (ASC) is used only in naturally ventilated buildings where occupants have different expectations, compared to those who stay in technically supported buildings, due to their adaptation to the external environment. The occupants are considered to do sedentary activities with a metabolic rate ranging from 1.0 to 1.3 met and clothing insulation is anticipated to 1 clo. Using the data from the free-running buildings alone, one arrives at the following relation between the indoor comfort temperature calculated from the data and the running mean of the outdoor temperature:

\[
T_c (°C) = 0.33T_{rm} +18.8
\]  

where, \(T_c\) is the predicted comfort temperature when the running mean of the outdoor temperature is \(T_{rm}\).

The 80% acceptability limits of indoor operative temperatures are estimated using Equations 2 and 3; while, the corresponding 90% acceptability limits is obtained by subtracting 1°C to the lower and upper 80% acceptability limit (BS EN 15251, 2007).

**Upper 80% acceptability limit (°C):** 0.33 \(T_{rm}\) +15.8  
**Lower 80% acceptability limit (°C):** 0.33 \(T_{rm}\) +21.8

**Field study results**

The recordings of the external wind environment show that the prevailing daytime wind flow (07:30-13:35) is north with an average wind speed of 1.7m/s and maximum wind speed of 3.2 m/s. The indoor-recorded field data shows zero air speed indicator in all classrooms due to a short single-sided ventilation.

The recordings were compared between classrooms pointing out slight differences, probably caused because of the different vicinity of the devices from the wall and windows. Table 3 shows the external conditions only during occupied hours i.e. 7:30-13:35 while Table 4 presents a compilation of the indoor record values of the same period.

| Table 3. External conditions during the monitoring period |
|---|---|---|---|---|
| **External conditions** | **Lowest record** | **Highest record** | **Average** | **St. Deviation** |
| **Week 1 10/02-13/02** | **Air temperature (°C)** | 10.9 | 17.9 | 14.4 | 2.3 |
| | **Relative Humidity (%)** | 49 | 83 | 66.6 | 11.1 |
| **Week 2 03/03-06/03** | **Air temperature (°C)** | 13.1 | 24.2 | 20.6 | 3.4 |
| | **Relative Humidity (%)** | 31 | 95 | 56.5 | 15.7 |
Table 4. Synthesis table of all recorded values

<table>
<thead>
<tr>
<th>Period</th>
<th>Parameter</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Room temperature (°C)</td>
<td>17.4</td>
<td>16.9</td>
<td>17.3</td>
<td>16.4</td>
<td>22.0</td>
<td>21.1</td>
<td>21.4</td>
<td>20.5</td>
<td>20.5</td>
<td>19.3</td>
<td>19.7</td>
<td>18.4</td>
</tr>
<tr>
<td>WEEK 1</td>
<td>Relative Humidity (%)</td>
<td>47.9</td>
<td>50.2</td>
<td>49.5</td>
<td>57.9</td>
<td>59.6</td>
<td>67.7</td>
<td>66.1</td>
<td>71.8</td>
<td>54.6</td>
<td>58.3</td>
<td>55.6</td>
<td>64.7</td>
</tr>
<tr>
<td></td>
<td>CO₂ concentration (ppm)</td>
<td>377</td>
<td>486</td>
<td>406</td>
<td>394</td>
<td>2669</td>
<td>3239</td>
<td>2087</td>
<td>2431</td>
<td>1328</td>
<td>1604</td>
<td>877</td>
<td>1047</td>
</tr>
<tr>
<td></td>
<td>Room temperature (°C)</td>
<td>19.7</td>
<td>19.7</td>
<td>19.7</td>
<td>18.3</td>
<td>24.6</td>
<td>22.4</td>
<td>23.6</td>
<td>22.6</td>
<td>22.8</td>
<td>21.4</td>
<td>21.9</td>
<td>20.7</td>
</tr>
<tr>
<td>WEEK 2</td>
<td>Relative Humidity (%)</td>
<td>41.2</td>
<td>36.0</td>
<td>43.3</td>
<td>37.8</td>
<td>70</td>
<td>73</td>
<td>68.9</td>
<td>77.7</td>
<td>55.6</td>
<td>55.2</td>
<td>58.4</td>
<td>60.3</td>
</tr>
<tr>
<td></td>
<td>CO₂ concentration (ppm)</td>
<td>417</td>
<td>416</td>
<td>407</td>
<td>409</td>
<td>2841</td>
<td>2989</td>
<td>2477</td>
<td>2357</td>
<td>859</td>
<td>1872</td>
<td>901</td>
<td>1372</td>
</tr>
<tr>
<td></td>
<td>St. deviation</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
<td>± 1500</td>
</tr>
</tbody>
</table>

Figure 3 shows the measured values of air temperature, relative humidity and concentration of carbon dioxide in classroom C3 during the first week of experimental monitoring for both weekdays and weekend. The results were presented in correlation to the external temperature and relative humidity as these factors can significantly affect the indoor conditions. The limit of CO₂ concentration at 1500ppm and the 80% acceptability limit of temperature are marked by the green line and light blue shadowed area respectively. Moreover, the figure portrays the period during which the classroom is supported by a technical heating system.

Based on Fig.3, CO₂ concentration levels during the weekend remain stable at about 420ppm while during weekdays, the IAQ parameters are not fulfilled despite the very high infiltration rate of 9.4 ach. During some mornings of occupied periods, CO₂ concentration values exceed 3000 ppm because the windows are closed during the teaching period to minimise heat losses. Nevertheless, Table 3 indicates that during the occupied periods, mean CO₂ values are not so high: varying between 877-1604 ppm with only one classroom (C2) exceeding the limit of 1500ppm. This is due to the fact that many classes remain unoccupied during the daily occupational period (7:30-13.35) which, in turn, results to lower mean values. As anticipated, the lowest values in all classrooms were recorded during night-time and early in the morning, during unoccupied time. During the afternoon session, the CO₂ concentrations were below the limit due to lower occupation density.

Considering that the monitoring process took place simultaneously in all classrooms, an immediate conclusion is evident in terms of temperature. Classroom C4 showed slightly lower temperatures compared to the others as it is more exposed to the external environment (Table 3). It is worth mentioning that the mean temperature values for classroom C2 and C4 were out of the reference interval (19.4-25.4°C) even though they were supported by technical heating, while classroom C1 and C3 barely met the acceptability limit. The mean external temperature for the period of the first experiment is 14.4°C (Table 3). All recorded values of mean relative humidity met the norms (Table 3) and a maximum value of RH of 71.8%
was only recorded in C4. It is notable that the indoor humidity trend in all classrooms showed an increase at the beginning of the occupied period (Fig.3).

1st Monitoring Period

The scenarios proposed in the first week of monitoring were based on the idea of minimisation of heat losses coming from ventilation during the winter period. For that purpose, windows were closed during the teaching period while single-sided ventilation strategies were performed only during break time for different times of the day in the four classrooms.

As indicated in Fig. 4 and Fig. 5, in an occupation period with 23-25 people, the CO₂ concentration reached the limit of 1500ppm and in most cases it even exceeded this limit. Specifically, in 15-20 minutes of occupation, the CO₂ increased above 1000 ppm (Fig. 5a); while for two consecutive periods with users, the CO₂ concentration reached double the limit creating an unpleasant environment. The drop of CO₂ levels in all classrooms is associated with the students’ departure from the classroom. However, if the classroom is unoccupied but closed the reduction rate is slow (Fig 5b).

Looking at the “save energy” scenario (Case 1 in C1) according to which the windows are always closed during the daily occupational period, the CO₂ concentration is over 1500ppm. The 20-minute break, during which the class is unoccupied, does not lead to a reduction of CO₂ below the 1000 ppm leading to a further increase of CO₂ values during the coming occupied period and to poor air quality. In a closed unoccupied classroom for one period (40 mins), the CO₂ concentration reduced from 1800 to 1300 ppm. Air temperature in C1 is the highest observed compared to other classrooms due to lesser heat losses through ventilation. A gradual temperature reduction of 1.5°C is observed by switching off the heating system.

Case 2 is also not effective in terms of indoor air quality as ventilation is provided only during the last 5-minute break when the heating system is switched off. As shown in Fig. 5, a peak of 3000 ppm is reached, while two consecutive periods need approximately 3 hours of empty space to reach a value below 1000ppm. Indoor temperature fulfils the comfort conditions when heating by a technical system is provided; then temperature drops below the acceptability limit and again meets the reference interval at about 13:00.

Case 3 shows improved CO₂ concentration compared to Case 1 and Case 2. A provision of 20-minute single-sided ventilation during the second break (10:30-10:50) reduced the CO₂ concentration by 1400ppm (from 2000ppm to 600ppm) without compromising thermal comfort and maintained air quality for the next periods. A small temperature fall is attributed to the switching off of the system. It seems that ventilation is required during every break time as the CO₂ concentration during the first break, when the classroom is closed, remains high.

Case 4 exhibits the best performance concerning indoor air quality. The CO₂ concentration decreased by 54% from 1386 to 642 ppm due to ventilation provided during the first 20-minute break. Moreover, it further decreased by 44% from 1850 to 1000ppm during the second 20-minute break, leading CO₂ concentration below the limit target. The temperature dropped by about 0.5°C during the first 20-minute break (8:50-9:10) while no variation was recorded compared to other classrooms during the ventilation provided in the second break. However, peak values of CO₂ during the monitoring reached approximately 3000ppm indicating that students cannot always identify poor air quality and that thermal comfort is probably the most important parameter in IEQ evaluation.
Figure 4. Indoor and outdoor temperature and CO\textsubscript{2} concentration profile of classrooms under the experiments Case 1- Case 4 at 12\textsuperscript{th} February 2018.

It is interesting to mention that when the classroom is closed and unoccupied, the CO\textsubscript{2} concentration needs 9-12 hours to return to the normal levels of 420ppm depending on the starting point (Fig. 5b).

Figure 5. CO\textsubscript{2} concentration profile in all closed classrooms (a) during occupied time and (b) during unoccupied time against time.

2nd Monitoring Period

The results of the first monitoring period highlight the significance of improving classroom ventilation. The next step in the study was to assess the effectiveness of different ventilation strategies in improving the ventilation rate in a way that would provide better indoor air quality in classrooms during the heating season. Three situations were assessed: (a) single-sided ventilation with some windows open during break time (C3_Case 7), (b) single-sided ventilation with all windows open during break time (C1_Case 5), and (c) cross ventilation with some windows open during break time (C2_Case 6). Continuous ventilation is considered (C4_Case 8) because previous results showed high CO\textsubscript{2} concentration during the teaching period.

Average values of indoor air temperature during the second week fall within the comfort zone. This is attributed to higher outdoor temperatures that showed a mean value of 20.6°C. In addition, the technical heating system enhances comfort between 7:00-10:00.

CO\textsubscript{2} concentration in C1, C2, and C3, during occupied time, reaches values above 1000ppm and in the case of two consecutive occupied periods, the CO\textsubscript{2} reaches values of
2500-3000ppm. CO₂ concentration in classroom C4 is below the limit of 1500ppm during the occupied time. This confirms the positive contribution of continuous ventilation during teaching periods. An increase occurs during the end of the day in the last two consecutive occupied periods where no adequate ventilation is provided in the preceding 5-minute break (Fig. 6_C4). This means there is not enough time to reduce the CO₂ below 1000ppm. The conclusion from this experiment is that the door alone cannot maintain IAQ when the classroom is consecutively occupied for two, or more, periods and when the ventilation provided before the occupation is less than 20 minutes. In such cases, additional shorter ventilation openings should be considered during the teaching period.

![Figure 6](image)

**Figure 6.** Indoor and outdoor temperature and CO₂ concentration profile of classrooms under the experiments Case - Case 8 at 6th March 2018

The effectiveness of different ventilation strategies is presented in Fig. 7. A 20-minute break is quite adequate to reduce CO₂ concentration. Cross ventilation (Case 6) gives a high ventilation rate causing a strong, quick fall of the indoor CO₂ followed by the case of single-sided ventilation combined with door opening (Case 8), followed by single-sided ventilation with all windows open (Case 5). The less effective strategy is the single-sided ventilation with some windows open due to the lowest ventilation rate (Case 7). Specifically, in a 20-minute break, Case 6 reduces CO₂ concentration from 3000ppm to 530ppm (82% reduction), Case 8 from 1270ppm to 460ppm (64% reduction), Case 5 from 2450ppm to 972ppm (61% reduction) and Case 7 from 1910ppm to 815ppm (57% reduction).

![Figure 7](image)

**Figure 7.** Effectiveness of different ventilation strategies on CO₂ concentration reduction against time for two different break times.
Conclusion

The objective of this paper is to investigate the indoor comfort conditions in a typical classroom of a secondary school in Cyprus and explore the impact of natural ventilation on both thermal comfort and air quality during the heating period. The study includes a comparative analysis of IAQ via CO$_2$ levels and thermal comfort via temperature and relative humidity of four south-oriented classrooms that adopted different ventilation strategies. The results highlight the effectiveness of an appropriate manual airing pattern regardless of the occupation density; indoor air quality is largely dependent on frequency and pattern of ventilation. Although airtightness of educational buildings is poor, CO$_2$ concentration levels are found to be exceeding the limit defined by standards when the classrooms are closed and occupied for two, or more, consecutive periods. The ventilation experiment has shown that the ventilation of classrooms is necessary during every break time to reduce concentration and preserve air quality. However, continuous ventilation, with a smaller air change rate through one window, or door, is also necessary during occupied periods. The results analysis shows that cross ventilation during break time leads to the quickest fall of CO$_2$ concentration compared to single-sided ventilation with some, or all, openings open.

Moreover, the study establishes that external environmental conditions affect greatly internal thermal comfort factors. Specifically, during unoccupied periods in weekends and without the support of technical heating, classrooms are out of the thermal comfort zone. During weekdays, when the mean outdoor temperature is below 15°C, classrooms remain in the comfort zone only during the time when they are supported by technical heating. All the recorded values of mean relative humidity meet the norms. It is thus, proposed that during the design process of the building, improvements on the energy efficiency features of the building envelope of educational buildings, as well as improvement on the airtightness, should be considered for optimum thermal comfort. Despite the fact that infiltration has a beneficial influence on the classrooms’ IAQ, it is a form of “uncontrolled” ventilation and hence, should be reduced on account of high-energy losses that affect negatively the energy performance of the building during the cold period.

A comparative analysis of the findings of the present study has enabled a scientific quantitative assessment that provides valuable knowledge vis-à-vis indoor air quality, passive ventilation and thermal comfort. The results produced give evidence to and quantify the efficiency of different ventilation strategies while, at the same time, they reveal the necessity for an appropriate manual airing routine and its impact on IAQ and thermal comfort. The present research reveals the positive influence of natural ventilation on IAQ in educational buildings in the hot and dry climatic conditions, not only of Southern Europe, but also of other areas with similar climatic conditions.

References


Assessing Energy use and Overheating risk for Retrofitting A Residential Tower Block Prototype in Northern Cyprus

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Abstract: This study evaluates the energy performance of a residential tower block (RTB) development in Northern Cyprus in providing thermal comfort for its occupants. Severe summer temperature conditions in the coastal city of Famagusta includes significant daily oscillations in air temperature (14°C-45°C) and high levels of solar radiation, which contributes to the overheating of thermally inefficient building envelopes. Notably, 43% of the domestic buildings in Northern Cyprus are RTBs. As could be expected in residential buildings located in a hot and humid climate the cooling and heating comprise the largest part of the total energy consumption (73%). The aim of this is to investigate the applicability of passive design elements for the case study using three representative residential tower blocks (RTBs) each representing a different orientation (south-west, south-east and north-west). The research adopts a ‘quantitative’ research design; primarily building performance evaluation using modelling and simulation. The selected three RTBs are modelled using Integrated Environmental Solutions (IES) software where extensive dynamic thermal simulations have been produced to test passive design measures applied to improve thermal comfort and energy performance. This paper presents an analysis of the thermal performance of the three RTBs before different retrofit scenarios are applied to optimize the buildings energy performance and occupants’ thermal comfort. According to the results of the dynamic thermal simulation, cooling energy consumption saving of around 81% are achieved. The findings demonstrate the necessity to consider passive design strategies for effective retrofitting of existing RTB developments in Northern Cyprus.

Keywords: Building performance evaluation, Dynamic thermal simulation, Overheating, Thermal Comfort, Retrofit.

Introduction

Many post-war European buildings were designed and built in accordance with criteria that typically lacks addressing reduced energy demand (Corrado et al., 2011). To date, many of these residential buildings have not undergone any retrofitting interventions; hence, the residential building stock is characterised by poor energy performance and thermal comfort issues. As per the European Council conclusions in the 2011 Energy Efficiency Plan, the residential sector is estimated to be responsible for 41% of all energy consumption in the European Union (EU) (EPISCOPE, 2016). Northern Cyprus is marked by a lack of standards, codes of practice and building regulations related to building energy performance; which does not help resolve issues of overheating of thermally inefficient building envelopes, particularly in post-war residential building stock (Sani and Ulucay, 2011). There are also no benchmarks for building energy performance, nor an official roadmap for regulating any ‘systematic retrofit’ to address energy efficiency (Serghides et al., 2016). The absence of energy conservation measures derives mainly from the fact that EU recommendations are not binding in Northern Cyprus (Ozarisooy and Altan, 2017). In 2015, the Town Planning Department, allowed architects to design buildings according to their clients’ requirements, taking into consideration only a limited number of guidelines related to the building thermal properties (State Planning Organisation, 2015). Yorucu and Keles (2007) note that construction-led growth has significantly changed the physical characteristics of the larger states in Northern Cyprus, particularly in the coastal town of Famagusta.

The present study aims to investigate the current energy consumption patterns of a number of representative flats in sample residential tower blocks (RTBs) in the city of Famagusta, Northern Cyprus as research case studies. The focus of this paper is on developing and testing passive design strategies aimed at optimising the thermal comfort of occupants whilst also reducing cooling energy
demands. The study seeks to identify the potential improvement of thermal comfort and reduced energy savings associated with passive design strategies through combinations of building fabric enhancement, appropriate shading and ventilation strategies. In this study, the applicability of passive design strategies has been extended to take into account and demonstrate how the orientation of representative RTBs and flat units become vital components in energy consumption, supported by the critical insights of occupants’ energy use variations. For this study, three different RTBs with different orientations (southwest [RTB1], southeast [RTB2] and northwest [RTB3]) have been selected. Sample flats on three different floor levels are investigated and evaluated in terms of their energy performance and occupancy patterns. The paper starts with a background of the research, followed by the research methodology, and the discussion of the results.

**Thermal comfort approaches and overheating risk assessment**

Several studies have been conducted on ensuring indoor comfort conditions and predicting the comfort level of building spaces in line with reference to European CEN BS EN 15251 (CIBSE, 2017). A number of works have been published evaluating the assessment methods related to the summer performance of unair-conditioned residential buildings (Ferrari and Zanotto, 2009; Nicol, 2017; Nicol et al., 2012). The adaptive approach is currently featured in the main international standards concerning thermal comfort (ASHRAE 2004; EN 15251 2007). With this in mind, it is usually considered the best assessment method related to the summer performance of unair-conditioned residential buildings. In fact, it is worth noting that, following the work of Humphreys (1978), de Dear and Brager (2001) and many others, there has been an increasing realisation that the predicted mean vote (PMV) model is inappropriate, especially in naturally ventilated buildings that are in free running mode, in hot and cold seasons. This has led to new formulations of various standards throughout Europe, including CEN standard BS EN 15251 (BSI, 2007), which includes 'adaptive' temperature limits for naturally ventilated or free running residential buildings.

It is fortunate that the ISO standard concerned with indoor environments (BS EN ISO 7730) is also used as an applicable benchmark for measuring nighttime ventilation in residential buildings. BS EN ISO 7730 provides a means for calculating both the PMV and predicted people discomfort (PPD) indices, together with some guidelines for the estimation of certain localised effects, such as shading and natural ventilation. Apart from that, Chartered Institution of Building Services Engineers (CIBSE) Technical Memorandum 52 has asserted that a new approach to the definition of overheating is necessary, particularly in residential buildings without mechanical cooling. This is in line with the methodology and recommendations of BS EN 15251 (BSI, 2007), which aimed to determine whether an existing occupied building can be classed as at risk of overheating, or whether a proposed building design may be in danger of becoming overheated, particularly in summer. As previously mentioned, within the greater Famagusta area, there is a high risk of overheating within its existing built environment (Ozarisoy and Elsharkawy, 2017). One pragmatic way of quantifying the effect of thermal comfort is defined in CIBSE TM52; it states that new buildings, major refurbishments and adaptation strategies should conform to Category II in BS EN 15251, as shown in Table 1 (BSI, 2007).

**Table 1. Overheating assessment criteria (CIBSE, 2016)**

<table>
<thead>
<tr>
<th>Assessment Criteria*</th>
<th>Acceptable Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria 1</td>
<td>Percentage of occupied hours during which $\Delta T$ (rounded to the nearest whole degree) is greater than or equal to 1°C</td>
</tr>
<tr>
<td>Criteria 2</td>
<td>Daily weighted exceedance (We) in any one day $&gt;6°C\cdot h$ (degree hours)</td>
</tr>
<tr>
<td>Criteria 3</td>
<td>Maximum temperature level ($T_{up}$) $\Delta T &gt; 4°C$</td>
</tr>
</tbody>
</table>

The chosen criteria for thermal comfort analyses in the present study are: Criterion 1: Percentage of hours above 33°C, Criterion 2: Percentage of hours above 35°C and Criterion 3: Percentage of hours below 18°C. To take into account the contextual features and simulation...
benchmarks of the representative RTBs, Criteria 1–3 all use indoor dry resultant temperatures. The percentages of hours are taken as the percentage of hours out of total hours in a year. It is important to note that the previously mentioned assessment criteria do not refer only to the occupied hours in each building, as exact information on occupancy patterns was difficult to find. Further, non-working family members are more likely to spend the afternoon inside than outside. For this reason, the assessments of all hours are based on the assumption that a representative flat unit should provide thermal comfort at all times of day. It is important to highlight that the temperatures 33°C and 35°C used to assess overheating were derived from the ‘CIBSE A’ criteria for overheating in the UK, which assigned maximum values of 5% and 1% for temperatures of 25°C and 28°C, respectively (CIBSE, 2017). These are clearly unsuitable for Famagusta’s hot and humid climate, which is the context of this study. As previously stated, adaptive thermal comfort model CIBSE TM52 was selected to take into consideration and assess performance against three criteria, yielding a classification of ‘overheating’ if a room fails to meet any two of the three criteria. A brief summary of the key indicators of the TM52 assessment method is mentioned here, but a more detailed explanation of the method can be found in IES’s TM52 descriptive explanation report (IES, 2017). The three criteria are: (a) Hours of exceedance:

The number of hours during which $\Delta T$ is greater than or equal to one degree ($^\circ K$) shall not be more than 3% of occupied hours. $\Delta T$ is defined as operative temperature [dry resultant temperature] less the maximum acceptable temperature [;

(b) Maximum daily weighted overheating exceedance: Assesses the severity of overheating across a day, in terms of both duration and magnitude of temperature, including its units are degree hours accordingly. Notably, it is weighted to account for both of these terms, with a value greater than 6°CChr resulting in failure in this criterion; and (c) Upper limit on temperature: Sets an absolute maximum value for indoor operative temperature where the maximum $\Delta T$ is set to 4°C (CIBSE, 2016). It is also important to note that the maximum acceptable temperature is the upper limit of the thermal comfort threshold. This is calculated as:

$$T_{max} = 0.33T_{rm} + 18.8 + SAR$$

where $T_{rm}$ is the exponentially weighted running mean of the daily mean outdoor air temperature and the suggested acceptable range (SAR) is 4°C (CIBSE, 2017), even though the maximum benchmark range suggested by the CIBSE as performance expectations is lower for the context of this study. A further method has been suggested in ‘CIBSE Guide A,’ BS EN 13779: Ventilation for buildings is an applicable performance requirement for ventilation and air-conditioning systems (CIBSE, 2016). This study takes into account basic definitions of thermal comfort benchmarks in occupied spaces and relates these to focus on the assessment of passive measures’ performance. This may require an assessment methodology to measure overheating in an occupied space. It is recommended that the approach to ‘overheating’ considered for measuring indoor thermal comfort be independent of the metric used to assess the energy performance of residential buildings; however, the more we can learn about the manner of both applicable and feasible passive design strategies put forward, the closer we will be to prioritising the most effective solution to overheating problems.

Research Methodology

Case study: Residential tower block (RTB) as a research case study

The primary underlying aim of the research is to investigate the impact of passive design strategies on energy use and to improve the energy efficiency of post-war residential buildings in
Famagusta, Northern Cyprus. Cyprus is the third-largest island in the Mediterranean, after Sicily and Sardinia. It is located in the eastern Mediterranean area and sits at latitude 35° North and longitude 33° East. According to the Köppen Geiger climate classification, Cyprus has climate characteristics that are typically Mediterranean, mostly a subtropical (Csa) type climate, with a partly semi-arid (Bsh) type in the northeastern part of the island (Kottek et al., 2006). In short, Cyprus is hot and humid during the summertime.

The research case study, Famagusta’s city centre residential estate, is a government-owned social housing development with 288 dwellings, facilities and commercial units for citizens with average incomes; as shown in Figures 1 (a), (b) and (c). The estate was built in the 1990s, and there are 32 RTBs with similar floorplan layouts and construction characteristics. The original U-values of the structure are 4.05 W/m²K for external walls, 2.94 W/m²K for the internal walls, 5.26 /m²K for the roof and 1.39 W/m²K for the windows and doors (Construction and Housing Statistics, 2013).

![Figure 1 (a) Selected Residential Tower Blocks (RTB1, RTB2 and RTB3) developed in 1990s; (b) The floorplan of the residential tower block; (c) The analytical energy simulation model of the RTBs. (Source: Researcher, 2017).](image)

The quantitative research design analyses the present energy performance of three representative prototype RTBs using building energy performance modelling and simulation methods. The dynamic thermal performance simulation studies of each building were carried out in an analytical energy simulation environment between May and September, during peak demand months for cooling energy. The assessment periods were spread throughout the summer, with the aim of measuring the risk of overheating. In each of the occupied zones (i.e., living, kitchen and bedroom spaces), were made of the characteristics needed regarding space energy use (naturally or mechanically), in order to take into account occupancy, electrical equipment energy use, space temperature, artificial lighting energy use and mechanical plant (A/C units) energy use. The aim of these studies was to capture a variety of space energy uses via relatively simple assessment benchmarks. Then, all data were imported into the IES simulation software to test the validity of the simulation results by embedding the CIBSE TM52 thermal comfort assessment add-ins to the IES software package. To create the model for the building performance simulation analyses—the set of information used to describe the overall building construction and occupancy schedules—a set of energy use data and a room data schedule that describes the occupancy patterns of the occupied spaces in the RTBs’ representative flats is developed, as shown in Table 2.

**Table 2.** Building features and simulation parameters of the prototype RTB (IES, 2017).

<table>
<thead>
<tr>
<th>Building Performance Factors</th>
<th>Internal heat gains in the simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of floors</td>
<td>5</td>
</tr>
<tr>
<td>Occupants: 3 W/m²</td>
<td></td>
</tr>
<tr>
<td>Area-to-volume ratio [m⁻¹]</td>
<td>0.33</td>
</tr>
<tr>
<td>Appliances equipment: 8 W/m²</td>
<td></td>
</tr>
<tr>
<td>Floor surface of a typical tested room</td>
<td>32.5 (m²)</td>
</tr>
<tr>
<td>Lighting: 2 W/m²</td>
<td></td>
</tr>
<tr>
<td>Room volume of a typical tested room</td>
<td>102.7 (m³)</td>
</tr>
<tr>
<td>Window size</td>
<td>1.5 x 1.2 (m²) per window pane</td>
</tr>
<tr>
<td>Exterior Window Ratio</td>
<td>0.21</td>
</tr>
<tr>
<td>Number of the subjects involved</td>
<td>1 male and 1 female (parents), 1 boy and 1 girl</td>
</tr>
<tr>
<td>Age of the subjects</td>
<td>Between 2 and 40</td>
</tr>
</tbody>
</table>
An initial observation exercise was undertaken for each prototype RTB. This involved reviewing the building plans, construction materials and feasible room schedules. A sample of three RTBs at three different site locations and orientations were investigated, for the following research stage to be based on the worst-case scenario with regards to overheating risk. The occupancy schedules for the flats is based on four people: one of them stays indoors throughout the day in the living room; all four occupants spend nights in their bedrooms. The air conditioning system schedule was considered for the cooling period between May and September based on the schedule of the occupants, in an attempt to obtain feasible results regarding energy consumption. The air-conditioning system’ set point is set at 23°C. Regarding the definition of air change rate, the reference parameters are assumed according to EN 15251 (2007). Once the parameters are defined, the Larnaca Airport - ASHRAE Climate Zone 4 weather file is used.

Results and Discussion: Residential Tower Blocks
Solar Analysis and Overheating risk assessment

Figures 2 a, b and c show the maximum solar radiation, when it occurs and the mean values for each floor level in the chosen RTBs. This Suncast simulation analysis demonstrates that the annual maximum number of hours during which surfaces are exposed to solar radiation occurs on the roofs’ surfaces (4382 hours), followed by the southwest facade of the buildings (3916.58 hours).

The total surface area of the exposed building envelope to solar radiation flux reaches a maximum value of 1524.78W/m²K during the year. There is relatively high absorption of this value by all of the three RTBs’ orientations, as the walls have absorptivity levels of 0.63–0.69. The inefficient building envelope absorbs a particularly high proportion of this solar radiation. Further, there are periods of relatively high solar gain during the year, with southeast-facing RTB 2 absorbing the highest heat gains through its building envelope (approximately 3916.58 hours). By contrast, southwest-facing RTB 1 absorbs slightly less radiant energy than RTB 2 (approximately 3862.66 hours), while RTB 3 absorbs approximately 3908.92 hours, due to its location on the ground floor and lower absorptivity levels. These findings highlight that high radiation gains, combined with an inefficient building envelope and a lack of shading systems, results in more overheating risks in southeast-facing RTB 2 when compared to southwest-facing RTB 1. This is not entirely due to solar gain, as it is the most susceptible to conduction gains due to its higher roof absorptivity, characterised by a high thermal transmittance value (5.26 W/(m²K)). Because of this, the CIBSE TM52 overheating criteria were assessed using the total number of days in a calendar year where the air temperature exceeds 6°C Hr while that zone was occupied (CIBSE, 2013). As previously stated in the literature, in compliance with Criterion 2, a zone should never exceed this value (CIBSE, 2017).
The results for the southeast-facing top floor spaces of RTB 2 are shown in Table 3. All occupied rooms significantly exceed the limit of Criterion 2. The flat on the middle floor shows worse thermal performance than the ground floor flat. Bedroom 2 in this unit is the worst performing occupied space, with a performance that exceeds the limiting factor by over three times, with a value of 22.5%. This trend is followed by the living room, with a value of 20.5%. Therefore, the flat at most risk of overheating is the south-east facing unit on the top floor of RTB 2 with three exposed external walls.

<table>
<thead>
<tr>
<th>Room Name</th>
<th>Occupied days (%)</th>
<th>Criteria 1 (%Hrs Top-Tmax&gt;=1K)</th>
<th>Criteria 2 (Max. Daily Deg.Hrs)</th>
<th>Criteria 3 (Max. ΔT)</th>
<th>Criteria failing</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE_GROUND_Livingroom</td>
<td>100</td>
<td>1.4</td>
<td>13</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>SE_GROUND_Bedroom1</td>
<td>100</td>
<td>3.1</td>
<td>23</td>
<td>5</td>
<td>1 &amp; 2 &amp; 3</td>
</tr>
<tr>
<td>SE_GROUND_Bedroom2</td>
<td>100</td>
<td>4</td>
<td>22.5</td>
<td>5</td>
<td>1 &amp; 2 &amp; 3</td>
</tr>
<tr>
<td>SE_GROUND_Bedroom3</td>
<td>100</td>
<td>0.4</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>SE_MIDDLE_Livingroom</td>
<td>100</td>
<td>3.4</td>
<td>20.5</td>
<td>4</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>SE_MIDDLE_Bedroom1</td>
<td>100</td>
<td>2</td>
<td>17</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>SE_MIDDLE_Bedroom2</td>
<td>100</td>
<td>4</td>
<td>22.5</td>
<td>5</td>
<td>1 &amp; 2 &amp; 3</td>
</tr>
<tr>
<td>SE_MIDDLE_Bedroom3</td>
<td>100</td>
<td>0.4</td>
<td>9.5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>SE_TOP_Livingroom</td>
<td>100</td>
<td>3.4</td>
<td>16.5</td>
<td>4</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>SE_TOP_Bedroom1</td>
<td>100</td>
<td>4.1</td>
<td>26</td>
<td>5</td>
<td>1 &amp; 2 &amp; 3</td>
</tr>
<tr>
<td>SE_TOP_Bedroom2</td>
<td>100</td>
<td>3.3</td>
<td>21</td>
<td>5</td>
<td>1 &amp; 2 &amp; 3</td>
</tr>
<tr>
<td>SE_TOP_Bedroom3</td>
<td>100</td>
<td>0.5</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

As the data above indicate, the flats exceed the appropriate limits, with the top floor flat showing the greatest risk of overheating. Within this flat, the living room surpasses 6°CChr, 16.5% of the occupied time, and bedroom 1 surpasses 6°CChr, 26% of the occupied time. This indicates that the occupied spaces within the flat are at relatively high temperatures throughout the year. Simultaneously, the flat on the ground floor has been found to perform better than those on the middle and top floors. Ground floor bedrooms 1 and 2 are observed as the critical occupied spaces within the flat that fail Criteria 1, 2 and 3. The differentiation in the performance of the occupied spaces on the ground floor is attributed to the airflow speed differentiation of the rooms. It is also important to note that the unit with two exposed walls has a reduced capacity for providing thermal comfort within the adaptive comfort limits. Bedrooms 1 and 2 in RTB 2 on the ground floor exceed 6°CChr, with values of 23% and 22.5%, respectively. The building’s indoor environmental conditions and thermal comfort in the summer are analysed and displayed in Table 4.

<table>
<thead>
<tr>
<th>Room Name</th>
<th>Temperature</th>
<th>Relative Humidity</th>
<th>PPD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max°C</td>
<td>Min°C</td>
<td>Max %</td>
</tr>
<tr>
<td>SE_GROUND_Livingroom</td>
<td>36.2</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_GROUND_Bedroom1</td>
<td>35.2</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_GROUND_Bedroom2</td>
<td>35.2</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_GROUND_Bedroom3</td>
<td>35.2</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_MIDDLE_Livingroom</td>
<td>35.2</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_MIDDLE_Bedroom1</td>
<td>34.4</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_MIDDLE_Bedroom2</td>
<td>35.4</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_MIDDLE_Bedroom3</td>
<td>35.1</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_TOP_Livingroom</td>
<td>36.4</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_TOP_Bedroom1</td>
<td>35.3</td>
<td>23.0</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_TOP_Bedroom2</td>
<td>36.1</td>
<td>22.3</td>
<td>100.0</td>
</tr>
<tr>
<td>SE_TOP_Bedroom3</td>
<td>35.6</td>
<td>23.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* The PPD max limit value is 15% - PPD is the percentage of people that will find the room thermally uncomfortable.
Table 4 shows the performance of each occupied space at three floor levels in terms of Criteria 1 and 2; the top floor flat outperforms the other floor levels. It maintains indoor temperatures above 34.4°C in all rooms for the entire year, only exceeding this number to reach 36.4°C. The highest temperature was observed in the living room of the top floor (36.4°C), while bedroom 2 experienced overheating with a temperature of 36.1°C. It is remarkable to note that all the occupied spaces in the three floor levels exceeded the benchmark of 33°C for thermal comfort criteria in Southern European countries (EN 15251, 2007). As for Criterion 1, the representative flat units are shown to exceed the limits of failure, with the corresponding top floor flat unit showing the greatest signs of overheating. In this flat, the living room surpasses 6°C/hr for 115 days, while bedroom 2 surpasses 6°C/hr for 77 days out of 365 days. Additionally, bedroom 1 in this flat on the top floor exceeds 4°C by 4 hours and 11 hours annually, respectively. This indicates that, for a significant proportion of the year, the flat will be extremely uncomfortable for its occupants. The results for both the ground and middle floors were also similar for each occupied space, with high Predicted people discomfort (PPD) levels. The results show that the indoor temperature follows a consistent pattern during the four weeks of August; however, important differences in absolute values due to outdoor conditions can be observed. The data demonstrates that the warmest and coldest weeks of August are the third and fourth weeks, respectively. This explains the differences found when temperature profiles are compared. Moreover, it must be highlighted that the indoor temperature is, in the majority of cases, greater than 32.5°C, at times reaching maximum temperatures close to 37°C.

The zones under consideration within RTB 2 were found to exceed the acceptable limits of two or more of the CIBSE TM52 criteria. The occupied spaces of concern are the two bedrooms, as they absorb the internal heat gains from the living room, from which one accesses these spaces. The occupied spaces with the poorest thermal performance were in the flat on the top floor. This is attributed to the thermal properties of the building envelope’s structural features. These occupied spaces (bedrooms 1 and 2) have two external walls, which allows for a higher heat transfer rate.

At all three floor levels, in each orientation and in relation to base case peak hourly cooling consumption (on a typical day in August between 06:00 and 00:00), the southeast-facing living room on the top floor has the highest cooling demand, with an increase of 21.69%, while bedroom 2 has a cooling demand of 21.60%. These values suppose an increase in cooling demand of 275.14 kWh/m² in the living room and 132.24 kWh/m² in bedroom 2. The southwest-facing bedroom 1 unit also has a higher energy demand, when compared to the southeast-facing bedroom 1 unit, in terms of cooling demand, with an increase of 25.84% on the middle floor and 24.16% on the ground floor. These values suppose an increase in cooling demand of 119.28 kWh/m² on the middle floor and 122.66 kWh/m² on the ground floor. Therefore, the southeast-facing bedroom 2 unit continues to be the orientation with the highest cooling demand, with an increase of 21.42% (132.24 kWh/m²) on the top floor and 21.10% (132.12 kWh/m²) on the ground floor, and a greater increase in cooling demand in the summer. By contrast, the northwest-facing top floor bedroom 3 unit can anticipate an increase in cooling demand of 25.05% (116.23 kWh/m²), while the demand is 22.46% in southwest-facing top floor bedroom 3 unit (114.46 kWh/m²). The simulation results of the existing performance for the representative RTB 2 indicated that the greatest share of the heat losses comes from air infiltration and exterior walls that lack insulation but have windows (provoking a high annual energy demand for cooling). Additionally, starting from these base case studies, when the adaptive set-point is used, a decrease in cooling demands due to additional ventilation is required, in particular for heavier construction materials and systems. During the peak cooling season, the summer, the occupied spaces reveal significant differences based on the adaptive temperature set-points of heavy weight construction materials, when the building envelope lacks thermal insulation.
**Retrofit strategies investigated in RTB 2**

The aim of analysing both the existing and retrofitted energy performance of RTB 2, as presented in this study, is to identify available building variants concerning the applicability of retrofit strategies and building envelopes. This is an important component of any building’s structure, as it is the interface between the interior of the building and the outdoor environment. By testing the current condition of thermal issues, we could determine that the building envelope plays an important role in regulating internal air temperatures and improving occupants’ thermal comfort levels. This also helps to determine the amount of energy required during the peak cooling demands of summer.

In addition to modelling and energy simulations, passive design strategies for retrofitting have been considered based on the building’s geometry, orientation, shading and type of construction material, as these affect the overall improvement of a household’s standard of living. The thermal and energy performance of the sample flat units were calculated using ApacheSim for dynamic thermal simulation calculations in IES software package. This analysis was split into six strategies, which consisted of sets of dynamic building energy simulations aimed at assessing the current energy performance of a typical flat unit, which is considered as the baseline design. The second strategy included the energy performance of a combination of passive design measures, including appropriate shading systems, external wall insulation on the roof and the more exposed walls and natural ventilation. The third strategy was a newly proposed architectural intervention for RTBs that includes a new fenestration design and the addition of operable external shading systems. The fourth, fifth and sixth strategies included adaptable passive design to evaluate the improvement in hours of discomfort. A list of the strategies in this building performance evaluation and optimisation study, including their methods for analysis and descriptions, are shown in Table 5.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Strategy Description</th>
<th>Analysis Method</th>
<th>Dynamic Building Simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base-case</td>
<td>Base-case Design</td>
<td>Energy Consumption Performance</td>
<td>Current assigned construction materials</td>
</tr>
<tr>
<td>Strategy 1 (S1)</td>
<td>Proposed Design</td>
<td>Energy Consumption Performance</td>
<td>Base-case design + Insulation on wall</td>
</tr>
<tr>
<td>Strategy 2 (S2)</td>
<td>Proposed Design</td>
<td>Energy Consumption Performance</td>
<td>Base-case design + Insulation on wall</td>
</tr>
<tr>
<td>Strategy 3 (S3)</td>
<td>Proposed Design</td>
<td>Energy Consumption Performance</td>
<td>Base-case design + Insulation on wall</td>
</tr>
<tr>
<td>Strategy 4 (S4)</td>
<td>Natural ventilation Analysis</td>
<td>Thermal Performance on living room, Bedroom 1, 2 &amp; 3</td>
<td>Base-case design Not Ventilated</td>
</tr>
<tr>
<td>Strategy 5 (S5)</td>
<td>Natural ventilation Analysis</td>
<td>Thermal Performance on living room, Bedroom 1, 2 &amp; 3</td>
<td>Base-case design Day Ventilation</td>
</tr>
<tr>
<td>Strategy 6 (S6)</td>
<td>Natural ventilation Analysis</td>
<td>Thermal Performance on living room, Bedroom 1, 2 &amp; 3</td>
<td>Base-case design</td>
</tr>
</tbody>
</table>

Table 5. Structure of the step-by-step applicable ‘retrofit strategies’ and those of the existing base-case.
The proposed solution for passive design retrofitting of the building envelope was the instalment of a thick, thermal insulated clay tile external facing system, the replacement of windows and door glazing (from single to ‘double low-e’ glazing) and using timber-framed shading elements. Combined, these should lead to a considerable reduction in heat loss through the building envelope. The presented scenarios were reviewed and studied globally, including the use of energy efficient building systems and local construction codes, and have yielded models of improvement that are particularly suitable for this region. Building energy retrofitting within existing envelopes provides substantial prospects for reducing energy consumption (Giannakopoulos et al., 2010). The retrofitting measures of the design alternative solution are as follows: exterior walls—existing outer layer removed, new 245-mm insulation was affixed to an inner layer and a new outer concrete layer, with external clay tile cladding installed (new U-value of 0.95 W/m²K); roof—old roof mastics and insulation were removed and new 340-mm insulation and a new asphalt mastic cover were installed (new U-value of 0.80/m²K); base floor—additional external insulation (new U-value of 0.94 W/m²K); and renewal of windows, balcony openings and internal doors—replace all existing single-pane windows with double-pane windows (new U-value of 1.39 W/m²K). Table 6 illustrates the assigned construction properties of the base case and the six strategies applied in the simulation.

Table 6. Specifications of the low-tech retrofit strategies and those of the existing base-case.

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Element Details</th>
<th>U-value W/m²K</th>
<th>R-value m²K/W</th>
<th>Thickness mm</th>
<th>Mass kg/m²</th>
<th>Thermal mass kJ/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base-case</td>
<td>Common Brick – HF-C4 + Brickwork [Inner Leaf] + Clear float 4mm</td>
<td>4.05</td>
<td>0.076</td>
<td>28.0</td>
<td>56.17</td>
<td>11.16</td>
</tr>
<tr>
<td>S1</td>
<td>Clay tile – HF-C1 + Vermiculite insulating brick + thermalite-high strength + Thermo-clear 8mm polycarbonate cladding + Clear float 4mm</td>
<td>0.95</td>
<td>0.88</td>
<td>110.5</td>
<td>83.32</td>
<td>34.6</td>
</tr>
<tr>
<td>S2</td>
<td>Asphalt mastic roofing + particleboard – High density + roof insulation + Thermo-clear 8mm polycarbonate cladding + Clear float 4mm + Insulation board – HF-B2 + Timber solar shield with adjustable blinds [500mm]</td>
<td>0.80</td>
<td>1.10</td>
<td>285.5</td>
<td>511.65</td>
<td>240.0</td>
</tr>
<tr>
<td>S3</td>
<td>Combination S1+S2 of envelope’s rehabilitation with shading and ventilation rate of 0.63 h⁻¹</td>
<td>0.80</td>
<td>1.10</td>
<td>285.5</td>
<td>511.65</td>
<td>240.0</td>
</tr>
<tr>
<td>S4</td>
<td>Combination S1+S2 of envelope’s rehabilitation with shading and ventilation rate of 0.4 h⁻¹</td>
<td>0.80</td>
<td>1.10</td>
<td>285.5</td>
<td>511.65</td>
<td>240.0</td>
</tr>
<tr>
<td>S5</td>
<td>Combination S1+S2 of envelope’s rehabilitation with shading, without passive night ventilation in summer and a constant ventilation rate of 0.4 h⁻¹</td>
<td>1.30</td>
<td>0.5</td>
<td>61.50</td>
<td>38.75</td>
<td>21.39</td>
</tr>
</tbody>
</table>

In terms of examining energy consumption with respect to specific heat losses, between May and September, the base-case southeast-facing top floor flat unit consumed 1143.9 kWh/m² of its energy during the pre-retrofitting phase and 8618.4 kWh/m² during the post-retrofitting phase. Additionally, the results of the base-case design on the most ill-performing southeast-facing flat in RTB 2 showed an annual energy demand for cooling calculated at 2081.35 kWh/m². The greatest gains were from solar energy absorbed through windows. Living rooms were the most affected, followed by the bedroom 1 units and the bedroom 2 units. At the same time, insulation in the roof strategy applied to the case study building’s envelope showed a greater percentage of improvement, compared to the base-case design. It is also remarkable to note that applying natural ventilation with shading systems and appropriate fenestration design onto the building envelope led to the lowest energy consumption, with an 81% improvement over the base-case design. Table 7 demonstrates the overall impact of the six implemented retrofit strategies on the cooling energy.
consumption and Percentage of People Dissatisfied (PPD), which, according to CIBSE TM52, should not exceed 15%.

**Table 7.** Simulation based cooling consumption and thermal comfort of the occupied rooms for the most-ill performing -east-facing RTB prototype during the pre and post retrofitting phases.

<table>
<thead>
<tr>
<th>Room Name</th>
<th>Cooling Consumption</th>
<th>Temperature</th>
<th>Relative Humidity</th>
<th>PPD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Retrofit Post-Retrofit</td>
<td>Pre-Retrofit Post-Retrofit</td>
<td>Pre-Retrofit Post-Retrofit</td>
<td>Pre-Retrofit Post-Retrofit</td>
</tr>
<tr>
<td>SE_TOP_Livingroom</td>
<td>1928.69 902.8</td>
<td>36.4 28.1</td>
<td>100.0 71.4</td>
<td>100.0 98.0</td>
</tr>
<tr>
<td>SE_TOP_Bedroom1</td>
<td>1709.09 836.7</td>
<td>35.3 25.9</td>
<td>100.0 74.6</td>
<td>99.1 98.0</td>
</tr>
<tr>
<td>SE_TOP_Bedroom2</td>
<td>2081.35 538.7</td>
<td>36.1 26.8</td>
<td>100.0 73.0</td>
<td>99.1 98.0</td>
</tr>
<tr>
<td>SE_TOP_Bedroom3</td>
<td>822.28 501.4</td>
<td>35.6 27.7</td>
<td>100.0 77.9</td>
<td>96.4 98.0</td>
</tr>
</tbody>
</table>

*The PPD max limit value is 15% - PPD is the percentage of people that will find the room thermally uncomfortable.*

The energy consumption for each passive design strategy applied to the base-case design on the southeast-facing top floor flat unit is shown in Table 8. As previously mentioned, the annual energy consumption of the base-case design was 2081.35 kWh/m². With a combination of systemic and passive design strategies applied, it decreased by 538.7 kWh/m². The fenestration design alone showed a decrease in the energy consumption, compared to the base-case design, of 57%. This is because the large-glazed balcony openings with solar shading systems were exposed to the sun, compared to the base-case design where the narrow openings were the ones exposed. Further, there were wide window openings in the living room of the retrofitted flat, compared to base-case design. It is also noteworthy that the solar gains received appropriately by the windows increased during the winter, due to the low solar angle. This design, using a combination of systemic and passive design strategies applied in Strategy 3 (S3), decreased the flat’s cooling energy consumption to 902.8 kWh/m². It is important to emphasise that insulating the exterior walls showed the greatest reduction in energy consumption. Depending on the location of a room and the ratio of the window area to the facade area, the insulation of the external wall reduced cooling energy use by up to 43% in the summer. The strategy of increasing the insulation layer thickness to greater than 200–300 mm led to only a small reduction in cooling energy use. In addition, the strategy of insulating the roof and floors depends strongly on the location of a given room. We observed that the replacement of roofing material reduced cooling energy use by 6–7%. At the same time, the replacement of windows reduced all occupied spaces’ energy consumption by 6%, because of the high thermal transmittance of U-value 1.1 W/m²K (double glazing with a low-emissivity coating). Additionally, adding 150 mm of insulation to floor surfaces improved occupants’ thermal comfort.

**Table 8.** Annual cooling energy consumption of base-case design and proposed strategies.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Energy Consumption (kWh/m²)</th>
<th>Percentage of Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base-case</td>
<td>2081.35</td>
<td></td>
</tr>
<tr>
<td>S1. Building envelope’s rehabilitation</td>
<td>1146.5</td>
<td>43%</td>
</tr>
<tr>
<td>S2. Building envelope’s rehabilitation + Solar shading systems</td>
<td>1084.5</td>
<td>52%</td>
</tr>
<tr>
<td>S3. Building envelope’s rehabilitation + Solar shading systems</td>
<td>902.8</td>
<td>57%</td>
</tr>
<tr>
<td>S4. Building envelope’s rehabilitation + Fenestration design</td>
<td>836.7</td>
<td>68%</td>
</tr>
<tr>
<td>S5. Building envelope’s rehabilitation + Fenestration design + Mechanical ventilation</td>
<td>735.4</td>
<td>72%</td>
</tr>
<tr>
<td>S6. Building envelope’s rehabilitation + Fenestration design + Mechanical ventilation</td>
<td>538.7</td>
<td>81%</td>
</tr>
</tbody>
</table>

*The results of the worst-ill performing southeast-facing Bedroom 2 unit on the top floor of the RTB2 (approximately 15 m²).*

The new appearance of the building envelope, with its adaptable openings and shading devices, was created to provide a controlled buffer zone for dealing with summer heat. For this purpose, the fenestration design was proposed, and it is evident that the greater effect of reducing the need for mechanical cooling was achieved. Retrofit technologies are specifically tested, verified and certified by the administrators for effective energy savings and offering comfortable environmental conditions (Santamouris, 2014). In this study, one essential element in the actions proposed was the top window openings on the flats’ balconies; these are set within the insulated
walls and provide adaptable, double-glazed openings to optimise sunlight and natural air ventilation. A ventilated facade was proposed, as it can reduce the amount of heat a building absorbs, due to the partial reflection of solar radiation by the existing large surfaces of window openings. The building component of the walls for the whole building consists of a ventilated facade with 3 cm of vacuum insulated panels (VIP), which lead to a U-value of 0.246 W/m²K. The outcome of these analyses is the conclusion that the most applicable and feasible retrofitting scenarios are thick thermal insulation, the implementation of a ventilated facade and the installation of solar shading systems.

As previously discussed, these three retrofitting strategies have great potential for use in developing an RTB, and, in particular, when designing nearly (or net) zero energy buildings. In short, these are state-of-the-art technologies. With the modification of the fenestration design in S3 and the implementation of a combination of systemic and passive design systems selected for the most ill-performing southeast-facing top floor flat in RTB 2, the energy consumption of the base-case design was the highest, due to an insufficient building envelope. This is because the new proposed strategies in Strategy 4 (S4) were based on harnessing natural ventilation, and they were effectively exposed to more solar gains. The proposed strategies were based on the principle of harnessing natural ventilation when there is no option of air-conditioning systems in the summer. This is because a previously conducted thermal performance analysis was used for the diagnosis of overheating risk and to analyse, accordingly, the hours of discomfort in each strategy. The evaluation of several passive design strategies for reducing overheating risk and optimising occupants’ thermal comfort over various retrofitting strategies needs to be investigated. To compare the overheating risk and comfort delivered by the retrofitting scenarios applied in the most ill-performing southeast-facing RTB 2 when there is no HVAC mechanical system for each case, a thermal performance assessment was made of the occupied spaces to calculate their hours of discomfort using the CIBSE TM52. For this study, six strategies were analysed to assess the efficiency of proposed building systems. Table 9 demonstrates the results of these overheating risk assessments based on the proposed six passive design strategies implemented in the base-case design for the most ill-performing top floor occupied spaces. These help us to determine which led to the best results.

Table 9. Optimisation-based summertime overheating results for the most ill-performing southeast-facing RTB 2 flat unit after retrofitting.

<table>
<thead>
<tr>
<th>Room Name</th>
<th>Occupied days (%)</th>
<th>Criteria 1 (%Hrs Top-Tmax&gt;1K)</th>
<th>Criteria 2 (Max. Daily Deg.Hrs)</th>
<th>Criteria 3 (Max. ΔT)</th>
<th>Criteria failing</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE.TOP.Livingroom</td>
<td>100</td>
<td>1.5</td>
<td>4.5</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>SE.TOP.Bedroom1</td>
<td>100</td>
<td>1.4</td>
<td>4.5</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>SE.TOP.Bedroom2</td>
<td>100</td>
<td>0.5</td>
<td>5.5</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>SE.TOP.Bedroom3</td>
<td>100</td>
<td>0.2</td>
<td>5.5</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>

By running the simulations for overheating and thermal comfort using each strategy (S1, S2, S3, S4, S5 and S6), we can declare several findings. Although all six strategies reduced both overheating risk and optimised the thermal comfort of occupants in the summer, S5 and S6 proved to be the most effective in addressing the three criteria of overheating, as shown in Table 9. The combination of S5 and S6 was also shown to improve indoor thermal comfort by reducing the indoor air temperature in the top floor living room from 36.4°C to 28.1°C (Table 7). However, Table 7 demonstrates the impact of all six implemented strategies on the PPD, which, according to CIBSE TM52, should not exceed 15%. As Table 7 reveals, PPD was reduced from 100% in the base-case scenario to 30.5% with the combination of S5 and S6, but this is still unacceptable and highlights the need for more building performance optimisation interventions.

Conclusion

This study undertook an in-depth investigation into the thermal performance of buildings and the occupants’ thermal comfort in residential tower blocks in Famagusta, Northern Cyprus. The
paper aimed to evaluate the risk of these structures overheating while also taking into account summertime cooling energy demands and potential ways to overcome them through the implementation of passive design strategies. This quantitative study was designed based on data collected from a dynamic thermal modelling and simulations conducted using IES software. The results from Suncast solar analysis software found that there are significant heat losses due to insufficient building envelopes and large glazed window openings. These finding provided strong evidence of overheating and high levels of thermal discomfort in all occupied spaces in three RTBs, particularly those on the top floor of the southeast-facing building (RTB 2), followed by several spaces in the building’s middle floor. Meanwhile, the Bedroom 3 units on three different floor levels, including the ground floor, appeared to remain within the comfort range throughout the overheating risk assessment evaluation period.

The subsequent investigative stage analysed the current thermal performance of southeast-facing RTB 2 and the potential retrofit solutions that could help to improve its occupants’ thermal comfort. The strategies incorporated into the most ill-performing spaces in RTB 2 showed that the building envelope’s rehabilitation in strategy 1 (S1) had the greatest impact on reducing cooling energy consumption, a 43% improvement, and that a 52% reduction can be achieved by a combination of building envelope rehabilitation and the implementation of the solar shading system featured in strategy 2 (S2), including horizontal external louvers and overhangs above large glazed window openings. The fenestration design of the RTB also had an impact on its energy and thermal performance, as was demonstrated in this study. The energy consumption of the RTB decreased by 57%, once the appropriate top window opening design, featured in S3, was applied. Nevertheless, these designs improved the ventilation of the RTB, allowing better thermal comfort for the occupants when the outside temperatures are lower than those inside. It is worth noting that the RTBs’ passive cooling systems should harness the prevailing winds, to allow for natural ventilation without neglecting the solar gains due to the climatic conditions of the research context. The fenestration design in S3 showed how allowing cross ventilation in all occupied rooms of the RTB leads to an increase in natural ventilation, thus providing more thermal comfort to occupants throughout the cooling season (May to September), without increasing the total gross area of the RTB, which would implicate higher costs.

Considering a combination of strategies 5 and 6, as implemented in the base-case RTB, we observed a net decrease in cooling energy consumption. Cooling consumption decreased by 81% when the outdoor air temperature was higher than indoor temperatures; this also matched a significant reduction of 538.7 kWh/m² in cooling load, which was dependent on solar shading implementation. It is important to highlight that increasing outdoor temperatures and consequently increasing the greenhouse gas emissions associated with rising energy consumption for cooling during hot, summer conditions will underdetermine the greater aims of climate change mitigation (Crawley et al., 2008). Less energy-intensive passive design strategies are investigated in this study, although the PPD remained higher than the thresholds stipulated in the current criteria (approximately 30.5–36.3%).

From a comfort and performance perspective, work completed in Mediterranean climates in the future should be designed to include solar shading appendages, as these proved to be the optimum retrofitting strategy. Solar shading systems can be implemented with little cost, given that they are a feature of climate change adaptation in this particular climate. As this study has demonstrated, it appears that passive design strategies can be both energy-efficient and cost-effective for retrofitting RTBs across Southern Europe. This is a crucial finding that needs further investigation to assess and optimise the risk of overheating and understanding occupants’ thermal comfort when enhancing feasible retrofitting scenarios in Mediterranean RTBs.
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Retrofitting improved environmental performance in refugee housing in Jerash Refugee Camp Jordan

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Abstract: Jordan is the second largest refugee host country in the world per capita. Around fourteen Jordanian refugee camps have transitioned from emergency shelters to permanent settlements, with Jerash Refugee Camp being one of the oldest and most deprived camps. The current housing in the camp is believed to be responsible for thermal discomfort and illness to its inhabitants. This study examined a retrofit strategy to improve occupant’s thermal comfort and indoor environment. Following a site visit, one house was selected and modelled digitally to represent a typical dwelling in the camp. This served as the baseline case against which to test the effectiveness of applying different several retrofit passive strategies, such as thermal insulation, natural ventilation, window size and passive heating, on the levels of indoor thermal comfort and indoor daylight quality. An epw weather file generated by Meteonorm for the camp’s location was used with the dynamic modelling software DesignBuilder, and PMV thermal comfort levels were analysed. Very low daylight levels in the house add to the poor environment and so daylight levels were evaluated using the Revit plug-in for Sefaira software. The results of the simulations showed that the proposed strategies did have an impact on the indoor thermal comfort values, especially the addition of thermal insulation to the building’s external envelope. The proposed passive strategies resulted in a shift in the hourly and daily-recorded PMV values to within the acceptable comfort range and an increase in the average daylight factor from 0.07% to 0.95%. The approximate cost estimation of the proposed retrofit strategy is around 21,243 JDs.

Keywords: PMV values, Thermal Comfort, Retrofit, Design Builder, Sefaira, Long-term refugee settlements

Introduction

The U.N. High Commission for Refugees, states that there are 19.5 million refugees worldwide. Moreover, 38.2 million people are relocated within their own countries. Jordan is ranked amongst the top 10 refugee hosting countries in the world. It is also categorized as the second largest host country in the world of refugees per capita. Nearly 41.2% of the country’s population is refugees, thus making it the home for approximately 2.7 million refugees. Jordan encompasses approximately fourteen refugee camps; the settlements were originally set as temporary emergency solutions. Generally, refugee camps are designed as short-term shelter solutions in response to a crisis. Nevertheless, it appears to be that the average life span of a refugee camp is 17 years. (Lahn et al. 2016) In Jordan most of the refugee settlements were created 40 years ago and remain present to date. Jerash refugee camp is a camp that was initially set up as a temporary emergency settlement back in 1968 and is occupied by 11,500 displaced Palestinian refugees. Located about 5km away from the ruins of Jerash, the camp covers approximately 0.75 square kilometres of land. The current statistics on Jerash Refugee camp show that the camp is a home for over about 24,000 refugees occupying 2,000 housing structures.

With time, the occupants altered the temporary structure of the shelters to create for themselves more durable dwellings. The building envelope that makes up the current housing structures at the camp consists of the following elements; concrete walls covered with corrugated zinc roofs and asbestos sheets. The houses are poorly insulated with no sufficient
daylight or proper ventilation. The structure of the housing is believed to be responsible for the cause of several diseases including cancer to its inhabitants. (FaFo Report, 2013)

The focus in this study is derived from the necessity to improve the permanent post-disaster housing conditions in Jordan. With the number of refugee camps increasing and the settlements changing from temporary emergency shelters to long-term permanent settlements there appears to be a need to create more resilient and durable housing structures that offer comfortable indoor environments to its occupants.

**Location of the Study**

Geographically, Jordan is situated in Southwest Asia. The capital of Jordan is Amman. This research studies Jerash Refugee camp, which is located in Jerash Governorate, Jordan. Jerash is situated in the North of Jordan, about 48 km away from the capital city Amman.

Given that Jerash Camp is the field of this study, an understanding of the region’s climate and geographical location must be established. This section outlines the location and climate conditions of Jerash Governorate, Jordan. Jerash’s climate is classified as a “Csa” by the Köppen-Geiger system, which is essentially a representation of “Warm Mediterranean climate”. The table below shows the monthly average temperature ranges for Jerash based on the epw weather files obtained from Climate Consultant. According to the climate analysis the hottest month of the year is July, and the coldest month is January.

<table>
<thead>
<tr>
<th>Monthly Means</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Bulb Temp. C°</td>
<td>8</td>
<td>9</td>
<td>13</td>
<td>16</td>
<td>21</td>
<td>24</td>
<td>26</td>
<td>25</td>
<td>23</td>
<td>20</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Dew Point Temp. C°</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>15</td>
<td>16</td>
<td>14</td>
<td>11</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

**Camp Overview**

The average size of the families living in the camp is seven members per family. The average income of each household is 100 Jordanian Dinars (JDs), which converts to approximately £110. The average annual electricity bill is 120 JDs, which breaks down to 10 JDs a month. In effect, occupants spend about 10% of their monthly income on electricity bills. According to the Committee to improve Jerash camp, the main issues the camp faces are extreme poverty, a high percentage of unemployment, and overcrowding. Furthermore, UNRWA states that about 3 out of every 4 dwellings are not suitable for housing due to structural problems. (FaFo Report, 2013)

The amenities available on the camp’s site are;
- Four schools in two buildings with two shifts. (Due to the large number of students.)
- One food distribution centre.
- One health centre.
- One community rehabilitation centre.
- One centre for women’s programs.
- One Development office for the camp

**Identifying the gap**
By observing the available examples of post-disaster settlements, a conclusion can be made that the energy performance of these structures is not efficient. When these settlements are built there is no consideration with regards to the sustainability and the durability of the housing structures. The available guidelines for post-disaster shelters are generic, with no specific regards to the settlements” location, climate, and cultural and social needs of the inhabitants. However, there is some recent research available regarding the implementation of sustainability and resilience in post-disaster settlements, for both temporary and permanent settlements. Nonetheless, there remains an evident absence for this consideration in permanent refugee settlements in Jordan.

**Research Aim**

The focus of the study will be on analysing the existing structures in Jerash Refugee Camp based on two indoor environmental factors; indoor thermal comfort and indoor daylight distribution. The study will investigate the impact of specific design parameters on the housing structures. This will be achieved by using the software DesignBuilder EnerPPlus for thermal comfort analysed based to Fanger’s PMV Index) followed by a daylight factor distribution using the software Sefaria. Improving the occupant’s thermal comfort levels essentially refers to controlling the indoor environment of the houses to offer an enhanced indoor environment to the inhabitants. The main issues in the camp of extreme poverty, poor housing conditions and electricity bills costing 10% of the occupant’s income, are factors that need to be taken into consideration (FaFo Report, 2013). Therefore, low-cost and technically simple interventions (i.e. insulation, double-glazed windows, shading overhangs, improved night ventilation) are proposed to encourage economic feasibility of improving the structures occupant’s comfort in this particular refugee camp. Selecting the suitable methods will be determined by factors such as the climate zone, and the availability of materials. The final part of this research presents an initial cost analysis of the suggested retrofit strategies.

**Thermal Comfort Analysis**

One of the most significant parameters of Indoor Environmental Quality is thermal comfort. Thermal comfort is defined as “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ANSI/ASHRAE Standard 55-2010) Effectively thermal comfort refers to how satisfied an occupant is with the thermal conditions within a space. This comfort can be associated with the geographic location and climate, time of year as well as occupant’s gender, race, and age. (Quang et al., 2014). Thermal comfort is considered a key factor in reducing a building’s energy consumption as it is believed that if occupants are not comfortable with the indoor environment they will resort to alternative methods of heating or cooling. In the 1960’s climatic chambers that controlled ambient air temperature, radiant temperature, air humidity and air stream velocity became more accessible. As a result, the assessment of these chambers led to the establishment of indoor human comfort indices to measure thermal comfort (Honjo, 2009). Ole Fanger was the first who developed a widespread model for thermal comfort. To date Fanger’s mathematical model is the most acknowledged thermal comfort index and is used in a number of standards and programs.

The predicted mean vote (PMV) is a thermal comfort index developed by Fanger in 1972. It is essentially a function of the following variables: air temperature; mean radiant temperature, air velocity, humidity, clothing resistance and metabolic rate. (Orosa, 2009, Sustainability Workshop, 2017)

The predicted Mean Vote (PMV) uses a seven point sensation scale (-0.3 < PMV < +0.3). The scale runs from -3 sensed as cold, to +3, sensed as hot. (designbuilder.co.uk, 2017, Autodesk
Sustainability Workshop 2017) This Index will be used to measure the thermal comfort for this research.

The following equation shows Fanger’s thermal comfort model that is used to calculate PMV:

\[
PMV = \left[0.393 - 0.006 M - 0.028 W + 0.007 M - 3.96E^8 f_{cl} ((t_r + 273)^4 - (t_c + 273)^4) - f_c h_c (t_d - t_c) - 3.05[5.73 - 0.007(M - W) - p_a] - 0.42[(M - W) - 58.15] - 0.0173M(5.87 - p_a) - 0.0014M(34 - t_a)]
\]

(Autodesk Sustainability Workshop, 2017)

With

\[
f_{cl} = \frac{1.0 + 0.2 I_{cl}}{1.05 + 0.1 I_{cl}}
\]

\[
t_{cl} = 35.7 - 0.0275(M - W) - R_{cl}((M - W) - 3.05[5.73 - 0.007(M - W) - p_a] - 0.42[(M - W) - 58.15] - 0.0173M(5.87 - p_a) - 0.0014M(34 - t_a))
\]

\[
R_{cl} = 0.155 I_{cl}
\]

\[
h_{cl} = 12.1(V)^{1/2}
\]

(Autodesk Sustainability Workshop, 2017)

Where

- \(e\) Euler’s number (2.718)
- \(f_{cl}\) clothing factor
- \(h_c\) convective heat transfer coefficient
- \(f_c\) clothing factor
- \(I_{cl}\) clothing insulation [clo]
- \(M\) metabolic rate [W/m²] 115 for all scenarios
- \(M\) metabolic rate [W/m²] 115 for all scenarios
- \(p_a\) vapour pressure of air [kPa]
- \(R_{cl}\) clothing thermal insulation
- \(t_{sa}\) air temperature [°C]
- \(t_{cl}\) surface temperature of clothing [°C]
- \(V\) air velocity [m/s]
- \(W\) external work (assumed = 0)

Methodology

To achieve the set research aim of “improving the occupant’s comfort and the indoor environment in long-term refugee houses in Jordan,” the following research methods were followed: Firstly, data were collected from secondary research such as case studies on existing refugee housing solutions, methods of achieving thermal comfort and low-cost retrofit projects. Investigating the existing knowledge was highly beneficial in forming the base of my research. A basic criterion for this research’s design proposal was achieved by combining concepts from other refugee housing as well as retrofit strategies.

Secondly, a site visit was taken to gather data on the existing housing structures, in the form of photographs, notes and sketches.

Thirdly, the digital mock-up model of the existing house was created to be tested using Design Builder EnergPlus. The model is based on the most typical dwelling structure found at the camp. Design Builder’s simulation engine is Energy Plus has enabled the author to attain precise records on annual, monthly, and hourly demands for each model, as well as indoor temperature values in housing units and the thermal comfort ranges. Followed by the natural daylight distribution within the structure study performed using the software Sefaria.

The Energy Plus simulation software is a tool used within Design Builder. Energy Plus is a thermal simulation software instrument that permits the investigation of energy performance throughout a building and helps determine the thermal load and energy consumption. The software tool simulates models for heating, cooling, lighting, ventilation, and occupant’s comfort. DesignBuilder EnergPlus simulations can generate a number of data on environmental conditions within the building and resultant occupant comfort levels. There are a number of comfort-related outputs that can be generated using Design Builder Energy...
Plus. One of the available outputs associated with comfort measurements is Fanger’s Predicted Mean Vote calculated based on ISO 7730 (Fanger PMV). This output was used for this study to establish the occupant’s comfort levels in the existing housing solutions as well as after applying the proposed retrofit methods. (designbuilder-v2.co.uk, 2017) Sefaira’s daylight analysis function provides day lighting and energy analysis that shows the daylight Factor visualization, and analyse the impact of the glazing ratios, window orientation, and shading strategies on the buildings performance.

The next step acquired was an analysis of the climatic data and the location of the camp. Based on that analysis the initial design strategies for improving the existing structure were proposed.

Next, following the analysis obtained from the climate study as well as the sustainable design approach of the three-tier system presented by Norbert Lechner, some passive basic building design methods were proposed to help improve the thermal comfort and energy performance those include; insulation, improving the walls thermal mass, changing the windows shapes and size to allow for more natural daylight, and shading. The analysis procedure followed is similar procedure to the one used by Heras et al. (2005) was followed. Heras et al monitored a number of buildings calculating indoor temperatures in the winter season as well as summer, investigated the level of thermal comfort reached in each period.

The strategies were added singularly and the model was simulated after every alteration to observe the impact of each strategy individually on the performance of the building. The simulations were run on the model to evaluate it in terms of its thermal comfort based on Fanger’s PMV Index. The final step included a brief cost analysis of the proposed design solutions.

**Analysis of Existing Structure**

**Building Geometry**

Provided that the current houses in the camp are a result of the occupant’s alterations to what was initially set as temporary housing solutions, the houses in the camp are dissimilar. However, the majority are constructed from the same materials; they have the same floor area and exterior render. The base line model for this research will be based on the most typical housing structure found in the camp. Almost every dwelling is made up from the following building elements; concrete walls covered with corrugated zinc roofs and asbestos sheets. The one-story structures each have a total floor area of 80-90m². As presented in the image below, the house is divided into an open space area which is generally used for storage, seating and in some cases an empty space that acts a buffer zone between the entrance the rooms. There are typically 2 bedrooms in each house that accommodate 3 to 4 people each.
Setting the Energy Model Parameters

Prior to running the energy simulations certain parameters need to be defined for the area of study. Weather data in the form of epw files were generated by Meteonorm based on the camp’s location “Jerash” were imported into DesignBuilder so that the simulations would be based on the climate conditions of the camp’s location. To design a sustainable building that consumes less energy the site’s climate should be taken into account as for it guides the designer in choosing the adequate passive strategies that are most effective for the specified site. The weather settings remained constant throughout the entire study.

Provided that the houses do not have an HVAC system, the heating and cooling set point temperatures, were set to 0°C. According to the Design Builder’s manual, the value of 0 indicates that the equipment is switched off, thus they will not be included in the simulations. (Designbuilder-v2.co.uk.2017). To represent the cracks and holes found in most of the houses in Jerash Refugee Camp, the airtightness settings were set to “crack template “ on the scale “very poor”. The remaining settings were kept as default settings.

Retrofit Strategy

Airtightness (Alteration 01)

Air tightness depends on the number and size of air leakage paths as well as the difference in air pressure between the inside and outside. By observing the external fabric of most of the housing structures in the camp it can be clearly predicted that the cracks in the external walls are a major source of air leakage. Air tightness will enhance the indoor comfort as well as the overall air quality. To improve the airtightness it is proposed that all cracks and openings in the external fabric should be fixed. This was represented in Design Builder by changing the cracked template from “poor” to “excellent” to resemble fixing the holes and cracks in the existing wall structure.

Insulation
For insulation a layer of Polystyrene boards with a thickness of 5 cm was added to reduce the thermal transmittance. The current wall structure in Jerash camp consists of uninsulated concrete block walls with an estimated U-value of 2.181 W/m. In a study Al Zyood et al. shows that a thermal insulation 5.7 cm and of trombe wall, is able to decrease a building’s heating requirements by approximately 82%. Therefore it is predicted that such a strategy will be effective in terms of creating a more comfortable indoor environment during the winter.

The parameters were changed in the DesignBuilder model were; the addition of a 5 cm thick polystyrene layer of insulation and exterior render to the walls. This improved the U-values to 0.50 W/m. Insulating the buildings envelope will help keep a constant indoor temperature all year round. By insulating the envelope, the structure will be protected against cold in winter and excess heat gain in summer. (Autodesk Sustainability Workshop, 2017)

**Apertures for Natural Ventilation & light distribution (Alteration 02)**

Due to the housing layout in Jerash Refugee Camp the massing and orientation of the housing structures is limited. Therefore, the proposed passive cooling strategy for this retrofit will investigate the impact of cross ventilation by placing opening on adjacent walls. As well as the daylight distribution within the dwellings.

For the baseline Model, the windows and openings placed where based on the analysis of the typical houses found in Jerash Refugee camp, about 3 windows per house. The sizes of the windows varied but the most typical ones were (0.5x0.5m) and (0.7mx0.5m). The proposal for Alteration 02 suggests an increase in the number and size of windows per house. The window to wall ratio chosen for this study is 20% total wall area of the south elevation. The size of the elevation represented in the mock-up baseline model is 42 m²; therefore, the total glazing area for that wall should be around 8 m². As for the West facing façade the total area is 21 m² therefore the total glazing area for that wall should be around 4 m². The chosen windows that will be placed are long horizontal strip windows in order to ventilate the space more evenly. Following the rule of thumb that states, “an area of operable windows or louvers should be 20% or more of the floor area, with the area of inlet openings roughly matching the area of outlets for an adequate amount of air to flow across the building.” (Autodesk Sustainability Workshop, 2017).

**Glazing Type**

The total floor area of the house is relatively 90m2, as a result the area of operable windows should be 18 ≥. Figure 3and4 shows the elevation views of the changes in the windows size and numbers. It should be noted that the model’s setting are set on ‘Calculated’ Natural ventilation Model option. Furthermore, the type of glazing was changed from single glazed to “double grey 6mm/6mm Air”.

![Figure 3 Elevation view of the digital model after the second alteration](image1)

![Figure 4 Elevation view of the digital model after the second alteration](image2)
**External Shading (Alteration 03)**

With the increase of the number of windows, the thermal analysis results for Alteration 02 have shown some values of discomfort during the summer analysis for the month of July, this can be a result of overheating due to increasing the area of glazing in the dwelling. Since increasing the size and number of windows has shown drastic improvements in the indoor daylight factor analysis they will remain the same. However, a proposed solution was to add external shading devices in the form of louvers above the windows External shading devices were integrated to the structure to prevent over-heating and maintain comfortable indoor temperatures.

**Simulation Results and Discussion**

The main objective of the proposed retrofit strategies is to improve the Occupants thermal comfort, therefore the simulations run measured and analysed the PMV thermal comfort levels. Design Builder’s simulation engine is Energy Plus; has enabled the author to attain precise records of annual, monthly, and hourly demands for each model, as well as indoor temperature values in housing units and the thermal comfort ranges based on Fanger’s PMV method. The output is referred to as **Pierce PMV SET** - the Predicted Mean Vote (PMV) calculated using the 'Standard' effective temperature and the Pierce two-node thermal comfort model. ([DesignBuilderOnlineManual, 2018](#))

In consonance with the epw weather analysis data obtained for Jerash, the lowest average temperatures fall in the month of January and the highest average temperatures are in July. Therefore the thermal comfort analysis periods for this study are the full months of January and July. These periods remained constant throughout the four simulations that were performed. The graph below shows the temperature records for the months of January and July. The following periods remained constant throughout the four simulations that were performed. The graph below shows the temperature records for the months of January and July.

![Figure 5 Graph showing the temperature records for January and July attained from Design Builder Energy plus](image)

**Simulation 01(Baseline Model)**

The graphs below presents the PMV values for the baseline model obtained from DesignBuilder during the month of January as well as the month of July. As mentioned earlier, the PMV is based on a seven-point sensation that runs from -3, sensed as cold, to +3, sensed as hot. The suggested adequate PMV range of thermal comfort for an indoor environment according to ASHRAE 55 is between the range of -0.5 and +0.5. ([AutodeskSustainabilityWorkshop, 2017](#))

![Figure 6 PMV Thermal Comfort Values for the baseline model, January and July](image)
It can be observed that most values fall outside the acceptable PMV comfort range of -0.5 to +0.5. According to Fanger’s PMV sensation scale the values below -0.5 are classified as slightly cool conditions and the values above +0.5 is classified as slightly hot. The initial simulations for the baseline model detected deficient indoor comfort conditions for the coldest and hottest months of the year.

There is a direct correlation between the outside temperatures, indoor temperatures and the PMV values. Where in January (coldest month of the year) recorded values indicate that as the outside temperature decreases the comfort value decreases to a colder sensation (-values).

The values for July (the hottest month of the year) show that as the temperatures increase the PMV values increase falling outside the acceptable comfort range, however this time moving towards a hotter sensation (+values). As a result of this observation the retrofit strategies aimed to keep the PMV values relatively constant despite the changes in exterior weather temperatures.

| July Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Baseline | 0.79 | 0.97 | 1.04 | 1.21 | 1.39 | 0.91 | 0.87 | 1.6 | 1.55 | 1.51 | 1.49 | 1.45 | 1.44 | 1.16 | 1.21 | 1.23 | 1.38 | 1.62 | 1.65 | 1.46 | 1.76 | 2.27 | 1.72 | 1.6 | 1.41 | 1.84 | 1.29 | 1.52 | 1.78 | 1.73 | 1.69 |
| Alt.01   | -0.09 | 0.12 | 0.15 | 0.14 | 0.42 | 0.06 | 0.08 | 0.22 | 0.33 | 0.35 | 0.35 | 0.34 | 0.24 | 0.24 | 0.25 | 0.29 | 0.36 | 0.4 | 0.34 | 0.34 | 0.58 | 0.59 | 0.5 | 0.43 | 0.36 | 0.34 | 0.43 | 0.51 | 0.54 | 0.53 |
| Alt.02   | 0.34 | 0.37 | 0.35 | 0.26 | 0.24 | 0.17 | 0.18 | 0.33 | 0.48 | 0.5 | 0.48 | 0.67 | 0.45 | 0.33 | 0.36 | 0.42 | 0.45 | 0.49 | 0.52 | 0.46 | 0.55 | 0.71 | 0.75 | 0.69 | 0.57 | 0.48 | 0.44 | 0.52 | 0.65 | 0.72 | 0.68 |
| Alt.03   | 0.21 | 0.26 | 0.25 | 0.18 | 0.14 | 0.06 | 0.11 | 0.26 | 0.38 | 0.43 | 0.41 | 0.89 | 1.75 | 1.25 | 1.25 | 1.29 | 1.36 | 0.42 | 0.47 | 0.41 | 0.52 | 0.62 | 0.67 | 0.63 | 0.51 | 0.4 | 0.37 | 0.47 | 0.58 | 0.62 | 0.59 |

Figure 7 Table of July PMV values for all models obtained from Design Builder Energy Plus

Looking at the PMV values demonstrated in the table above in figure 5, it can be observed that during the month of July all values baseline values fall outside the comfort range. As for the month of January more than 85% of the values fall outside the comfort range. This is indicated by the blue colour, which highlights all the values falling outside the comfort range. Therefore it can be agreed upon that the current dwellings situation is causing discomfort to its occupants during the coldest and hottest months of the year.

**Results for Simulation 02 (Alteration 01)**

The indoor comfort levels are directly affected by the outdoor temperatures, therefore to maintain acceptable indoor comfort values the objective would be to ensure that the indoor temperature remains in the acceptable comfort range regardless of the outdoor weather conditions. Alteration 01 focused on improving the airtightness of the exterior envelope by ensuring the exterior walls have no cracks. As well replacing the corrugated zinc roof with a concrete insulated roof structure. Also by adding a layer of 5cm thick polystyrene insulation board to the exterior walls. (Al-Hinti and Al-Sallami, 2017) The addition of the insulation board and the fixing of the cracks in the walls resulted in a major shift of almost all the PMV values towards the acceptable comfort range. This is shown in Figure 5 where most of the values are highlighted in yellow. Despite the major shift in the comfort levels towards the acceptable range, the addition of openings and glazing was highly recommended due to the poor daylight transmittance observed during the site visit.
**Daylight Factor Analysis**

The levels of natural daylight transmittance in a space are critical to create an adequate indoor environment that is comfortable to its occupants. There are several benefits attributed to suitable daylight levels in an indoor space. Firstly, a well-lit space has on impact on the occupant’s phycology, where sufficient daylight can stimulate both the human visual and circadian systems. Secondly, facilitating daylight transmittance into an indoor space offsets artificial lighting, which consequentially saves energy. Moreover, it has a positive impact on the inhabitant’s performance, attentiveness, and makes the environment more comfortable for people to undertake day-to-day tasks.

Visual observations were made during the site visit to Jerash Refugee Camp that the houses lacked sufficient daylight due to the low number of windows, the distribution of the windows and the small sizes of the windows in the houses. The images in Figure 6 below show an example of the quality of daylight inside the houses during the afternoon period.

The results of the daylight analysis simulations performed using Sefaira have shown that daylight factor analysis supported the visual observations made on site as the daylight factor for the baseline model is 0.07%, which is far below the acceptable range of 2%. After the alterations of the openings and apertures were applied a shift in the average daylight factor was observed from 0.07% to 0.95% As shown below;

**Results for Simulation 03 (Alteration 02)**

The proposal for Alteration 02 suggests an increase in the number and size of windows per house. The chosen windows to be placed are long horizontal strip windows in order to ventilate the space as well as to allow for more natural light to enter the space. Furthermore, to create more daylight distribution the addition of a skylight is proposed. The placement of the skylight follows the “Skylight-to-Roof Ratio (SRR) that is the net glazing area divided by the gross roof area. A rule of thumb1 is that the SRR should be between 3% and 6.”(Autodesk Sustainability Workshop, 2017) Area of the skylight = \((3 \times 1.5)^2 \times 5\% = 0.9m^2\)

Referring back to the results displayed in figure 7, it is shown that during the July period the increase in the glazing area, the size and the number of windows some PMV values have slightly shifted outside the acceptable comfort range. This can be a result of the increase in the heat energy penetrating the structure through the glazing. Nonetheless this has only been observed in the simulation results during July (summer period). Furthermore, this is observed
during 10 out of 31 July days and during 6 out of 31 January days. Provided that the strategy appears to effect the summer month more by shifting the values to a slightly hotter sensation, the aim of the next proposed strategy was to ideally reduce the indoor temperatures during the summer period while maintaining the same comfort level during the winter season.

Results for Simulation 04 (Alteration 03)

The addition of the external shading devices has caused an insignificant shift in the PMV values, as it can be observed in Figure 7, final row. In comparison with the results for Alteration 02 the values do not seem to shift to the comfort range. Therefore, there appears to be no need to include that in the retrofit strategy, as the impact is not that evident.

Cost Analysis Table

<table>
<thead>
<tr>
<th>Building Element</th>
<th>Unit Price</th>
<th>Quantity Required</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closing the gaps and openings</td>
<td>5 JDs / m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall Plastering and Render</td>
<td>4.5 JDs/m³</td>
<td>36.8 m²</td>
<td>15 JDs</td>
</tr>
<tr>
<td>5 cm Polystyrene Insulation Layer</td>
<td>70-80 m²</td>
<td>122.4 m²</td>
<td>9,792 JDs</td>
</tr>
<tr>
<td>Creating New window Openings in Concrete walls</td>
<td>60 JDs / m²</td>
<td>6 openings 2x0.9 m²</td>
<td>676 JDs</td>
</tr>
<tr>
<td>Standard Double Glazed Window</td>
<td>50-60 JDs / window with Aluminium frame</td>
<td>6 windows</td>
<td>360 JDs</td>
</tr>
<tr>
<td>Ceiling and roof Installation</td>
<td>100-110 JDs per m²</td>
<td>80-90 m²</td>
<td>9,990 JDs</td>
</tr>
<tr>
<td>Skylight Opening Single glazed</td>
<td>70-80 JDs m²</td>
<td>1 m² opening</td>
<td>80 JDs</td>
</tr>
</tbody>
</table>

Total: 21,243 JDs


The following cost estimate is an approximation based on the current prices in Jordan provided from a few local suppliers. It should be noted that this is only a rough estimation that is included to provide a rough cost estimation of the strategies as an initial starting point. The quantities are based on the proposed retrofit fit strategies explored throughout this research.

An estimated cost of the Typical Houses in the camp is calculated as a comparison, the values were obtained from the Jordan Green Building Council “Green Affordable Homes Project and are according to 2 local builders and Al Yanabea’ CBO in Ajloun. The cost analysis shows that the proposed design strategies will potentially cost 51.2% more than the traditional construction method adopted at the camp. (Visser,2018)

Table 2 Cost Analysis of the Typical Construction Methods Adopted by the occupants at the Camp

<table>
<thead>
<tr>
<th>Elements</th>
<th>Unit Price</th>
<th>Total Price of Required Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block layers</td>
<td>Single layer 80JDs/ M2</td>
<td>9,792 JDs</td>
</tr>
<tr>
<td>Plaster finishes</td>
<td>4.5 JDs/m³</td>
<td>330 JDs</td>
</tr>
<tr>
<td>3cm Thermal Insulation (Roof, Wall, Floor)</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Single Glazed (Dbl. Glazed -17JDs)</td>
<td>40 JDs per window</td>
<td>240 JDs</td>
</tr>
</tbody>
</table>

Rough Total Cost of Construction 10,362JDs

Conclusion

This study examined a retrofit strategy to improve occupant’s thermal comfort and indoor environment. After analysing the available literature on retrofit projects, a number of
researches agree that the energy performance of existing buildings can be enhanced significantly through improving the thermal insulation of the building envelope (efficient windows, low u-values of walls). This statement was particularly valid in the case of this study. The most evident impact on the occupant’s thermal comfort was observed after Alteration 01, which consisted of increasing the insulation levels in the wall and roof structures to meet the requirements set by Jordanian Green Building Standards. The research concludes that the proposed passive strategies excluding the addition of external shading has resulted in a shift in the hourly and daily-recorded PMV values to within the acceptable comfort range and an increase in the average daylight factor from 0.07% to 0.95%. The approximate cost estimation of the proposed retrofit strategy is around 21,243 JDs, with the roof and the addition of insulation being the highest cost. To determine the economical feasibility of the study the next step would be to analyse the energy loads of the dwellings and compare the energy consumption of the proposed strategies to the typical construction method. Following an economical payback period calculation, which will determine the exact payback time and thus show the economical practicality of the proposed retrofit strategy.

References


Websites

Local Suppliers
Waddah Al-souki Consulting and Engineers. / Jordan Polystyrene Company. / Al Saif Industrial Co, Al Hirafiyeen St 21, Amman /Jordan Insulation Materials Company, JIMC.
Field Studies on Thermal Comfort Environment in Building Transitional Space

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² Associate, Sustainability and Building Physics, Buro Happold International (Hong Kong) Limited

Abstract

Transitional spaces have been widely applied in building designs nowadays, which are presented in the form of atria, lobbies, corridors and covered streets. As they have become common features, they account for 10%-40% of the total volume of a building. However, maintaining an acceptable thermal comfort within transitional spaces poses challenges to building designers and engineers, as thermal discomfort has been revealed in such spaces of several newly constructed buildings. This paper aims to investigate the thermal environmental performance and people’s adaptive comfort in building transitional spaces by conducting field studies. On-site questionnaire surveys and physical measurements, were carried out during the summer period of 2017 and the winter period of 2018 in three selected case buildings in Cardiff, including The National Assembly for Wales – Senedd, Hadyn Ellis Building and Royal Welsh College of Music and Drama. The total responses collected from the questionnaire surveys during the summer period and the winter period were 736 and 580 respectively. This paper first presents the findings from the field studies. In-depth investigations on the human adaptability to thermal environment were then conducted, which identified strong correlations between the clothing value and the indoor operative temperature of transitional spaces. Regarding the open question on actions that people would take to overcome uncomfortable situations, nearly 80% of the respondents opted for self-adaptive actions when facing uncomfortable situations. The research work concluded that a fine control on indoor temperature for maintaining acceptable comfort level within building transitional spaces is not necessary due to people’s adaptability to thermal environment.

Keywords: Transitional spaces, thermal comfort, field studies, questionnaire survey, adaptability

1. Introduction

Nowadays, transitional spaces are integrated into the different kinds of building design. Transitional spaces are claimed as “unavoidable spaces in non-domestic buildings”, which occupy about 10% - 40% of the total volume in different types of buildings (Pitts & Saleh, 2006). Pitt & Saleh defined transitional spaces as the spaces located in-between outdoor and indoor environments, which provide both buffer spaces and physical link (Pitts & Saleh, 2007). With the transitional spaces serving as environmental bridges, connection between the interior and exterior environments, along with relaxation spaces are provided for occupants to enjoy the surroundings. In these spaces, occupants are able to experience the dynamic effects of external climatic changes. (Taleghani, et al., 2014). Different purposes can be served by transitional spaces, including seating area, circulation passage, entrance lobby, cafeteria and meeting places (Ilham, 2006). From the architectural aspect, transitional spaces can be attached or unattached to a building development (Monterio & Alucci, 2007).

Although transitional spaces do not require fine control of temperature or comfort limits, maintaining an acceptable thermal comfort for such space is still a challenge to the building designer (Pitts & Saleh, 2007). Recent researches revealed that thermal discomfort is a big issue for transitional spaces. Moreover, there is still a lack of research evidence on thermal environment of transitional spaces (Monterio & Alucci, 2007; Hui & Jiang, 2014; Rupp,
et al., 2015). The majority of previous research on comfort environment with dynamic states, including transitional spaces like corridors and atria, were conducted in climatic chambers, and only a few of them have been validated through fieldwork studies (Palma, 2015). Most of these studies only cover human thermal response to stable environment conditions (Liu, et al., 2014). This may be the reason why transitional spaces are still not clearly addressed in current comfort standards (van Hoof, 2008), where no recommended acceptable indoor temperature ranges have been specified for thermal comfort in transitional spaces (Yu, et al., 2015).

This paper aims to investigate the thermal environmental performance and people’s adaptability in building transitional spaces by conducting field studies which include on-site questionnaire surveys and physical measurements.

2. Research Methodology

The methodology adopted in this research included on-site questionnaire surveys and physical measurements in three existing buildings in Cardiff – The National Assembly for Wales – Senedd (NAfW), Hadyn Ellis Building (HEB) and Royal Welsh College of Music and Drama (RWCMD), as shown in Figure 1. Prior to the confirmation of the proposed methodology for the main studies in these three buildings, a pilot study was performed in Optometry Building of Cardiff University on 21st July 2017. The pilot study was thoroughly reviewed, including the feedbacks that were obtained during the process. The proposed methodology was then optimised prior to carrying out the main studies. For the field study portion, during the conduction of questionnaire surveys, the indoor and outdoor environmental conditions were monitored simultaneously.

![NAfW, HEB, RWCMD](image)

Figure 1. Surveyed buildings and their indoor environments

2.1 Surveyed Buildings

The selected buildings spread out across the city of Cardiff, where the distance from the outdoor weather station ranges from 0.1km to 2.8km. The functions of these buildings were greatly different but all were open to the public during open hours. The windows were designed to open automatically through the control from Building Management System (BMS), to enhance the ventilation during warm days in order for a more desirable thermal
comfort level to be maintained within the buildings. In each of the selected buildings, 3 days in both the summer and winter period were spent to carry out the field studies respectively, consisting of questionnaire surveys and physical measurements. Table 1 summarises the key characteristics of the surveyed buildings.

<table>
<thead>
<tr>
<th>Surveyed building</th>
<th>NAFW</th>
<th>HEB</th>
<th>RWCMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building established</td>
<td>2006</td>
<td>2012</td>
<td>2011 (refurbished)</td>
</tr>
<tr>
<td>Building type</td>
<td>Public / Government</td>
<td>Academic</td>
<td>Academic / Cultural</td>
</tr>
<tr>
<td>Building area</td>
<td>5,120 m²</td>
<td>9,740 m²</td>
<td>4,400 m²</td>
</tr>
<tr>
<td>No. of stories</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Major façade type</td>
<td>Glazed</td>
<td>Glazed</td>
<td>Glazed</td>
</tr>
<tr>
<td>Windows open strategy</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
<tr>
<td>Distance from weather station</td>
<td>2.8km</td>
<td>0.6km</td>
<td>0.1km</td>
</tr>
<tr>
<td>Survey dates (Summer Time)</td>
<td>19 August 2017</td>
<td>4 August 2017</td>
<td>20 September 2017</td>
</tr>
<tr>
<td>Survey dates (Winter Time)</td>
<td>6 January 2018</td>
<td>1 February 2018</td>
<td>20 January 2018</td>
</tr>
<tr>
<td>Survey period</td>
<td>10:30 – 16:30</td>
<td>08:30 – 17:30</td>
<td>08:30 – 19:00</td>
</tr>
</tbody>
</table>

2.2 Physical Measurements

While the questionnaire survey was carried out, the indoor environmental parameters which include air temperature, relative humidity, air velocity and black globe temperature were monitored. The accuracy of the instrumentations used for the field studies complies with the requirements of ASHRAE 55-2013 (ASHRAE, 2013).

Table 2 summarises the details of the instrumentations that were used in the field studies. Measurements covered the indoor transitional spaces, including entrance lobby, atrium and café area. To ensure that the readings were representative throughout the surveyed area, measurements had been taken in different locations within a space to identify the best measurement location. The air speed was measured at 15-minute intervals while all other parameters were monitored at 1-minute intervals. The measurement locations were set at 1.1m height from the floor. For the outdoor environmental parameters, data were recorded every 5 minutes by a weather station installed on the rooftop of the Bute Building, the Architectural School of Cardiff University. The model of the weather station was Campbell Instruments CR10 data logger. The air temperature and relative humidity were measured by Rotronic temperature and humidity probe in a radiation shield.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Instrumentation model</th>
<th>Range</th>
<th>Accuracy</th>
<th>Accuracy requirements ASHRAE 55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>Tinytag Ultra 2 Temperature and Relative Humidity Logger</td>
<td>-25°C - 85°C</td>
<td>±0.5°C (for range 0-40°C)</td>
<td>Minimum: ±0.5°C Ideal: ±0.2°C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Tinytag Ultra 2 Temperature and Relative Humidity Logger</td>
<td>0% - 95%</td>
<td>±3% (at 25°C)</td>
<td>±5%</td>
</tr>
<tr>
<td>Black-globe temperature</td>
<td>Tinytag Talk 2 Temperature Logger (with 40mm black table-tennis ball)</td>
<td>-40°C - 125°C</td>
<td>±0.4°C (for range 0-70°C)</td>
<td>Minimum: ±2°C Ideal: ±0.2°C</td>
</tr>
<tr>
<td>Air speed</td>
<td>Lutron AM-4204 Anemometer</td>
<td>0m/s - 20m/s</td>
<td>±0.05m/s (for up to 1m/s)</td>
<td>±0.05m/s</td>
</tr>
</tbody>
</table>
2.3 Questionnaire Surveys

A standardised questionnaire was developed to collect subjective data from the building occupants for comfort evaluation in the specified locations of the surveyed buildings. 24 questions were included in the questionnaire, which adopted a combination of open-ended, partially closed-ended and predominantly closed-ended questioning approaches. 7-point scale and 5-point scale methods were adopted for the thermal sensation questions and the thermal and sunlight preference questions respectively. Furthermore, in order to understand people’s adaptability to thermal environment, an open question of “how would you overcome uncomfortable situations, if any” was designed in the questionnaire. Additional data collected from the questionnaire included demographic data, activity level, clothing insulation, time spent in interviewed location, previous space locations, time spent in previous space, feedbacks and previous thermal experience in the interviewed location. Building users were randomly selected within the transitional spaces of the surveyed buildings to carry out the questionnaire survey.

2.4. Data Analysis

The data collected from the field studies were first compiled into spreadsheets and later analysed using Statistical Package for Social Sciences (SPSS) version 23. Data were separately analysed according to the surveyed buildings and specified locations within the buildings. In order to assess the correlation between pairs of variables, Pearson correlation coefficients were computed. The significance level of the analysis was set to be 0.05. In other words, the results were statistically significant when p-value < 0.05.

3. Results and Analysis

3.1 Descriptive Analysis

<table>
<thead>
<tr>
<th></th>
<th>NAFW</th>
<th>HEB</th>
<th>RWCMD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer</td>
<td>Winter</td>
<td>Summer</td>
</tr>
<tr>
<td>Total responses (N)</td>
<td>282</td>
<td>198</td>
<td>207</td>
</tr>
<tr>
<td>Male respondents</td>
<td>110 (39%)</td>
<td>90 (45%)</td>
<td>81 (39%)</td>
</tr>
<tr>
<td>Female respondents</td>
<td>172 (61%)</td>
<td>108 (55%)</td>
<td>126 (61%)</td>
</tr>
<tr>
<td>Age</td>
<td>Mean</td>
<td>42</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Clothing value (clo)</td>
<td>Mean</td>
<td>0.50</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.17</td>
<td>0.33</td>
</tr>
<tr>
<td>Activity level (met)</td>
<td>Mean</td>
<td>1.44</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.48</td>
<td>0.47</td>
</tr>
<tr>
<td>Outdoor temperature (°C)</td>
<td>Mean</td>
<td>18.14</td>
<td>5.39</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.30</td>
<td>1.40</td>
</tr>
<tr>
<td>Indoor temperature (°C)</td>
<td>Mean</td>
<td>20.85</td>
<td>15.95</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.32</td>
<td>0.78</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>Mean</td>
<td>43.60</td>
<td>44.67</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>5.26</td>
<td>4.17</td>
</tr>
</tbody>
</table>

* Temperatures shown were the record taken during the time when the questionnaire survey was conducted

The total number of responses collected from the questionnaire surveys were 736 and 580 during the summer period and the winter period respectively. Throughout the summer period, 282, 207 and 247 surveys were contributed by the NAFW, HEB and RWCMD respectively;
throughout the winter period, 198, 155 and 227 surveys were contributed by the NAfW, HEB and RW CMD respectively. As the building functions and settings in the indoor transitional spaces of these buildings varied, the monitored and surveyed figures were different in each building. Details are summarised in Table 3.

The NAfW is a government building that is open to the public. During the summer period, given that a special event “Poppies – weeping window” was held during the surveyed period, a significant number of respondents from the survey were visitors to the building. No special events were held during the winter period, which might have resulted in the reduced number of collected surveys. The average activity level of the respondents was higher than the other two surveyed buildings owing to a larger portion of visitors who were watching the exhibition or appreciate the building architectural design or functional use of different parts of the building.

The HEB is an institutional research building that provides facilities such as offices, laboratories, meeting spaces, seminar and lecture rooms for university students or researchers to carry out various types of academic activities. As most of the respondents were undergraduate and postgraduate students, the average age of the respondents was lower than that of the NAfW. Due to a higher portion of respondents used the transitional spaces for resting and dining, and with more chairs and sofas set up for the building users, more respondents’ major activity in the transitional spaces was sitting when compared to the NAfW. Therefore, the average activity level was lower than the NAfW.

For the RW CMD, as the academic term started when the questionnaire survey was being carried out, a greater number of respondents were undergraduate and postgraduate students when compared to the HEB. Therefore, the average age of respondents from the RW CMD was the lowest among all the surveyed buildings. Given the large number of chairs and tables provided for the building users in the atrium space and café area under study, the average activity level of the respondents was the lowest when compared to the other two surveyed buildings, where the respondents were mainly sitting with little physical movements. Most of the respondents used the transitional spaces for waiting, resting and meetings.

Figure 2 illustrates the frequency distribution chart of the thermal sensation votes (TSV) that were collected from questionnaire surveys in the three surveyed buildings – the NAfW, HEB and RW CMD during the summer period and the winter period. The thermal sensation distribution was similar among the 3 surveyed buildings for both periods, where the majority of respondents voted “neutral” for the thermal comfort with others feeling on the warmer side.
For the summer period, about 85%, 83% and 76% of the respondents were found in the 80% acceptability comfort band \((-1 \leq TSV \leq +1)\), as defined by ISO 7730:2005 (ISO, 2005), for the NAfW, HEB and RWCMD respectively. In addition, for the question about overall thermal feeling of the building, about 94%, 82% and 91% of the respondents felt pleasant (i.e. voted for +1 or higher) for the NAfW, HEB and RWCMD respectively.

For the winter period, the number of respondents that were found in the 80% acceptability comfort band was reduced when compared to the summer period. They were about 82%, 81% and 78% for the NAfW, HEB and RWCMD respectively. Similarly, the number of respondents who felt pleasant about the overall thermal feeling of the buildings was also reduced in general, except for the HEB. About 88%, 91% and 82% of the respondents voted pleasant for the NAfW, HEB and RWCMD respectively.

3.2 Correlation Analysis

In order to evaluate the correlation between different parameters and filter out the couple of parameters that detailed analysis shall be carried out, Pearson (2-tailed) correlation analysis was conducted in the SPSS software. Only the pairs of parameters that have significant statistical correlation were chosen for detailed analysis, which included the clothing value versus indoor operative temperature and outdoor temperature, and the TSV versus indoor operative temperature or outdoor temperature. Table 4 below summarises the correlation results between clothing values and the temperature data and that between TSV and the temperature data respectively. The correlation was considered to be statistically significant for \(p<0.05\); and more statistically significant for \(p<0.01\).

It was found that clothing value correlated better with indoor operative temperature than with outdoor temperature. The relationship was stronger for the NAfW and the RWCMD during the summer period and the winter period.

| Table 4. Correlation results for clothing values of all surveyed buildings |
|---|---|---|---|---|
| **Clothing Value** | **NAfW** | **HEB** | **RWCMD** |
| **Summer** | **Winter** | **Summer** | **Winter** | **Summer** | **Winter** |
| **Indoor Operative Temperature** | -0.384** | -0.145* | -0.260* | -0.185* | -0.145* | -0.312** |
| **Outdoor Temperature** | -0.386** | -0.144* | -0.072 | -0.125 | -0.107 | -0.146* |

*significant at \(p<0.05\)

**significant at \(p<0.01\)

3.3 Investigation of Influence of Indoor Operative Temperature and Outdoor Temperature on Clothing Value

The reported respondents’ clothing in the questionnaire surveys were converted into numerical values with reference to ASHRAE Standard 55-2013 (ASHRAE, 2013) and ISO 7703:2005 (ISO, 2005). In order to reduce the impact of outliers in the database, binning method was adopted by taking the weighted averages for the sample size within every half-degree-Celsius bin. Figure 3 illustrates the linear regression plots between the average clothing value and the indoor operative temperature and outdoor temperature respectively.
For the correlation of clothing value against indoor operative temperature, the linear relationship was strong, with the coefficient of determination ($r^2$) ranging from around 0.71 to 0.91. Negative gradients were identified for all cases. In other words, the higher the indoor operative temperature, the lower the clothing value.

Similar correlations were conducted between clothing value and outdoor temperature. Similar relationships between outdoor temperature and clothing value were identified, with the correlation being weaker than the comparison against indoor operative temperature. The coefficient of determination ($r^2$) ranged from 0.23 to 0.41. The identified gradients were the same, which were negative, as the correlations against indoor operative temperature.

![Clothing Value vs Indoor Operative Temperature](image1)

![Clothing Value vs Outdoor Temperature](image2)

![Clothing Value vs Indoor Operative Temperature](image3)

![Clothing Value vs Outdoor Temperature](image4)

![Clothing Value vs Indoor Operative Temperature](image5)

![Clothing Value vs Outdoor Temperature](image6)

Figure 3. Influence of indoor operative temperature and outdoor temperature on clothing value (summer period)
For the correlation of clothing value against indoor operative temperature, the linear relationship was strong, with the coefficient of determination ($r^2$) ranging from around 0.76 to 0.83. Negative gradients were identified for all cases. In other words, the higher the indoor operative temperature, the lower the clothing value.

Similar correlations were conducted between clothing value and outdoor temperature. Similar relationships between outdoor temperature and clothing value were identified, just that the correlation was weaker than the comparison against indoor operative temperature. The coefficient of determination ($r^2$) ranged from 0.16 to 0.22.

Figure 4. Influence of indoor operative temperature and outdoor temperature on clothing value (winter period)
3.4 Investigation of Actions that People Would Take to Overcome Uncomfortable Situations

An open question was asked in the questionnaire in regards to how the respondents would act to overcome uncomfortable situations. For the summer period, out of the 736 surveyed questionnaires in total for the 3 surveyed buildings, the response rate for this question was 320, or 43.5%. For the winter period, the response rate for the question was 259, or 44.7% for the 580 collected surveyed questionnaires. Some respondents provided more than one answer. 339 and 298 answers were collected from the respondents for the summer period and winter period respectively. Given that one of the questions was open-ended, the use of words was different with each answer but they can basically be grouped into 9 categories, which are “adjust clothing”, “use mechanical means”, “drink/eat”, “move/leave from the uncomfortable location”, “report to building staff”, “do exercise”, “close the openings”, “improve the architectural design” and “other”. For example, answers such as “take off jackets”, “add a layer of clothing” and “put scarf / cardigan on” were classified as “adjust clothing”; answers such as “have a cup of coffee”, “eat a burger” and “drink water” were grouped into “drink/eat”; and rare answers such as “talk my way through” and “more light” were classified as “other”. Table 5 summarises the details on the actions that respondents would take to overcome uncomfortable situations.

Out of these categories, “adjust clothing”, “drink / eat”, “move / leave from uncomfortable location” and “do exercise” can be treated as self-adaptive actions. Nearly 90% of the respondents opted for self-adaptive actions to overcome uncomfortable situation. In other words, a vast majority of people tend to adapt themselves to the thermal environment to make themselves feel more thermally comfortable rather than approaching to change the building operations.

<table>
<thead>
<tr>
<th>Categorised actions</th>
<th>NAFW</th>
<th>HEB</th>
<th>RWCMD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer</td>
<td>Winter</td>
<td>Summer</td>
<td>Winter</td>
</tr>
<tr>
<td>Adjust clothing</td>
<td>55 (54%)</td>
<td>50 (46%)</td>
<td>43 (44%)</td>
<td>37 (59%)</td>
</tr>
<tr>
<td>Move / Leave from the uncomfortable location</td>
<td>23 (23%)</td>
<td>14 (13%)</td>
<td>14 (14%)</td>
<td>12 (19%)</td>
</tr>
<tr>
<td>Use mechanical means</td>
<td>11 (11%)</td>
<td>19 (17%)</td>
<td>12 (12%)</td>
<td>5 (8%)</td>
</tr>
<tr>
<td>Close the openings</td>
<td>1 (1%)</td>
<td>0 (0%)</td>
<td>16 (16%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Drink / Eat</td>
<td>4 (4%)</td>
<td>13 (12%)</td>
<td>4 (4%)</td>
<td>4 (6%)</td>
</tr>
<tr>
<td>Other</td>
<td>2 (2%)</td>
<td>2 (2%)</td>
<td>4 (4%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>Report to building staff</td>
<td>2 (2%)</td>
<td>1 (1%)</td>
<td>3 (3%)</td>
<td>3 (5%)</td>
</tr>
<tr>
<td>Do exercise</td>
<td>3 (3%)</td>
<td>6 (6%)</td>
<td>2 (2%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Improve the architectural design</td>
<td>0 (0%)</td>
<td>4 (4%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Total response rate</td>
<td>101 (30%)</td>
<td>109 (37%)</td>
<td>98 (29%)</td>
<td>63 (21%)</td>
</tr>
</tbody>
</table>

Table 5. Summary of respondents’ actions to overcome uncomfortable situations
4. Discussions

The data analysis showed that the thermal comfort level was highly acceptable by the building users. A large portion of respondents (>82% for both the summer and the winter periods) voted the overall thermal feeling as “pleasant” (>+1 vote) in all the 3 surveyed buildings. Moreover, more than 80% of the respondents voted the TSV within the 80% comfort acceptability band (-1≤TSV≤+1). Even though variations of the indoor temperature were greater than 4.5°C, the comfort level of these buildings did not vary too much.

Correlations between the clothing value and the indoor operative temperature and outdoor air temperature respectively were also investigated for both the summer and the winter periods. Similar trends were identified from both correlations, where the correlation between the clothing value and indoor operative temperature was stronger. It can be explained that people would choose the appropriate clothing according to the outdoor air temperature before they went out. By then, after they entered the space where they felt thermally uncomfortable, they would adjust their clothing to adapt themselves to the thermal environment to make themselves feel more comfortable.

This statement was supported by the investigations of the open question which asked about the actions that the people would opt to take to overcome uncomfortable situations. The distributions of the voted actions were similar for the summer and winter periods. Almost 80% of the respondents would take self-adaptive actions, including “adjust clothing” (50% for summer; 53% for winter), “Move / Leave from the uncomfortable location” (21% for summer; 16% for winter), “Drink / Eat” (5% for summer; 6% for winter), and “Do exercise” (2% for summer; 3% for winter), to keep themselves warmer or cooler when they felt cool or warm. Therefore, it can be concluded from this research study that in order to maintain an acceptable thermal comfort level in indoor transitional spaces, people would act to adapt to the thermal environment to make themselves feel comfortable and thus fine control of indoor temperature is not necessary for transitional spaces. Therefore, a fine control of indoor temperature is not necessary for transitional spaces.

5. Conclusions

Investigations on the thermal comfort of building transitional spaces were carried out by this research work. Field studies, which included questionnaire surveys and physical measurements, were conducted in three selected buildings in Cardiff during the summer period in 2017 and the winter period in 2018. They were The National Assembly for Wales – Senedd, Hadyn Ellis Building and Royal Welsh College of Music and Drama. A total number of 736 and 580 responses collected from the building occupants during the summer period and the winter period were analysed respectively.

A vast majority of the respondents from the surveyed buildings expressed pleasant overall thermal feeling with the environment in transitional spaces. Although there was slight difference in a number of factors such as age, activity level, indoor temperature and clothing values, similar thermal sensation vote was identified, where 76% - 85% and 78% - 82% of the respondents fell within a comfort acceptance band (±1 sensation) for these surveyed buildings for the summer period and the winter period respectively.

Further investigations were carried out to evaluate the human thermal adaptability by correlating the reported clothing value against indoor operative temperature and outdoor temperature respectively. Linear relationships were found for both comparisons, where the
correlation was much stronger for the impacts of indoor operative temperature on clothing value. It may imply that people would adjust their clothing by checking the outdoor air temperature before they went out, and they would fine-tune their clothing as they entered the indoor environment according to their thermal sensation.

In addition, actions that people would take to overcome uncomfortable situations were also investigated. The answers from the respondents were grouped into 8 categories, which were “adjust clothing”, “drink/eat”, “move/leave from the uncomfortable location”, “do exercise”, “use mechanical means”, “report to building staff”, “close the openings” and “other”. The first four categories were treated as self-adaptive actions. The response distribution for the summer period and the winter period was similar. About 80% of the respondents opted for self-adaptive actions to overcome uncomfortable situation. This further explained the strong correlation between clothing value and indoor operative temperature. The higher the operative temperature, the less clothing value was reported in the questionnaire surveys. In other words, people would tend to wear less when the indoor operative temperature rose, or vice versa. Understanding the human adaptability to its thermal environment, fine control of indoor temperature is not necessary for maintain acceptable thermal comfort in transitional spaces. On the basis of this research, further research works on quantifying the comfort temperature range and methods to provide all-year-round comfortable environment in transitional spaces are recommended.

It was concluded from this research that a fine control of the indoor temperature to maintain the thermal comfort for the building occupants is not necessary for building transitional spaces. On the basis of the research, further research works about the impacts of the architectural and mechanical system designs on the thermal environment are recommended in order to maintain acceptable thermal comfort for the building occupants in building transitional spaces.

Acknowledgement

The authors would like to express their gratitude to the National Assembly for Wales – Senedd, Hadyn Ellis Building and Royal Welsh School of Music and Drama for the great support to the research work. Not only did they lend the spaces for the field studies, their building management teams also provided great technical assistance for the data collections and measurement setups.

References


Investigating resident experiences of a sustainable social housing development in the composite climate of Delhi

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²Development Alternatives, New Delhi, India.
³The Energy and Resources Institute (TERI), New Delhi, India.

Abstract: The Government of India aims to construct 12 million social housing dwelling units through the Housing for All by 2022 programme. It is vital to identify what the impacts and benefits of housing production at such a massive scale could be. This is no easy task in an inherently data poor environment. This paper describes the methodology and learnings from a field survey of 149 residents in a social housing development for local industry workers in Delhi, constructed using modular perforated bricks and flyash. The purpose of the resident survey was to gather subjective feedback from residents about their perception of the indoor environmental conditions (indoor temperature and air quality) in their homes during summer and winter using a rating scale. The survey results showed that residents perceived indoor temperatures in summer to be much more unsatisfactory than in winter. Only 12% of respondents rated their indoor conditions as ‘satisfactory’ in summer, whereas the same proportion rated it as ‘unsatisfactory’ in the winter. This indicates the inability of the dwelling units to provide comfortable indoor environment in the summer (in absence of air-conditioning). However in winter, higher levels of adaptation occurs wherein residents resort to warm clothing and blankets, along with a reduced heat loss due to small size/exposure of the dwelling units. Air inside dwellings was perceived to be still by one-third of occupants, though still air was desirable in winters. The lack of cleanliness and absence of maintenance regime was also evident from garbage accumulation and water logging in the open areas and along the streets in, and around the development, resulting in unhygienic living conditions. The study is part of a United Nations funded research project on mainstreaming sustainable social housing in India.

Keywords: Economically Weaker Section (EWS), social housing, householders’ survey,

Introduction

In recent times, housing shortage – particularly in the urban areas, has emerged as one of the most critical issues confronting India (KPMG and NAREDCO, 2012). Majority of this is attributed to the growing rate of rural to urban migration, which in turn has rendered stress on the existing basic amenities and infrastructure. According to an estimate by The Ministry of Housing and Urban Affairs (MoHUA) the total urban housing shortage at the end of 2017 was about 10 million, with more than 95% of this pertaining to the houses for the Economically Weaker Sections (EWS) and Low Income Groups (LIG) (Jones Lang Lasalle, 2018). Through its “Housing for All by 2022” mission, the Government of India intends to close this gap by aiming to construct 12 million social housing units over the programme duration (2015-2022) through a combination of slum upgradation projects in partnership with the private sector, direct government-led housing delivery, a credit-linked subsidy scheme as well as support to beneficiary-led construction (MoHUA, Govt. of India, 2017).

The construction sector in India is energy and material intensive, contributing to about 22% of the total GHG emissions in the country (Reddy B.V., 2009). The future growth in this sector would therefore require not only human and financial resources at an unprecedented scale, but natural ones, too. This represents both a grave danger in terms of environmental degradation, but also an opportunity for introducing life-cycle thinking into the building sector and promoting economic inclusion for millions.
Several studies have revealed the need to use energy efficient materials and building techniques to achieve sustainable development and better thermal performance of low cost housing in India (Bardhan and Debnath, 2018). Research work on identifying the energy efficient features (Chandel et al., 2016) and thermal performance of vernacular dwellings (Singh et al. 2010) using extensive literature review, site monitoring and occupant surveys have revealed the satisfactory thermal performance of these dwellings. However, these come with issues of durability and require higher maintenance (Chandel et al., 2016). Nix et al. (2015) investigated the indoor temperature, relative humidity and residents’ feedback in 13 self-build dwellings in an informal settlement outside Delhi in the winter period. The research found that the monitored dwellings were unable to provide adequate comfort temperatures during winter, and indoor temperature was significantly affected by the roofing material. Research on field studies of thermal comfort in middle class naturally ventilated dwellings (Indraganti, M. and Rao, K.D., 2010) have shown a weak effect of age group and gender on the residents’ thermal comfort sensation. The impact of housing construction on social sustainability and well-being of the residents was studied in a study conducted by Karuppannan and Sivam (2011). Three different neighbourhoods with different urban forms were compared to establish the relation between urban form and social sustainability at a neighbourhood level, in Delhi India. However there is limited empirical evidence pertaining to the performance and sustainability of EWS or LIG housing from the residents’ perceptive. It is this gap that this paper seeks to address.

This paper describes the methodology and learnings from a field survey of 149 social housing residents in a housing development for local industry workers in Delhi (Bawana housing development), constructed using modular perforated bricks and flyash. The purpose of the resident/householder survey was to gather subjective feedback from residents about their perception of the indoor environmental conditions (indoor temperature and air quality) in their homes during summer and winter, along with aspects of maintenance and upkeep of the development, familiarity with the building materials, and access to basic day to day necessities around the development.

In India, the term ‘social housing’ has been more commonly referred to as ‘affordable housing’ (EWS and LIG) by the Government and housing experts alike. However, ‘affordability’ of housing can vary depending on the income level. In this study therefore, the term ‘social housing’ has been used instead, to signify housing which serves the housing needs of LIG and EWS with the provision of ensuring access to physical, social, environmental and financial well-being (Herda, G., et al., 2017). The present study is part of an ongoing UN Environment funded research project ‘Mainstreaming Sustainable Social Housing in India Project’ (MaS-SHIP) which seeks to integrate sustainability in social housing projects.

**Methods and case study**

To gather empirical data on the perception of householders of the selected social housing development, the following methods were adopted (1) *Interview based questionnaire survey* (2) *Observations of researchers* (3) *Photographic survey* of the dwellings and surroundings to capture the existing conditions.

The survey questionnaire was designed based on Likert scale and consisted of questions (Table 1) on the following aspects: Indoor environmental conditions; Daylight and ventilation; Experience with the building materials and technology; Affordability; Maintenance and upkeep of the common areas; Accessibility to basic public facilities. While designing the questionnaire, careful consideration was given to the sociological and educational
background of the respondents. To assess householder perception of indoor environment, easy-to-understand questions on the perception of ‘indoor temperature and indoor air’ were included, and the rating scale was also therefore limited to a scale of three (Table 1, Perceived indoor environment in summer and winter). Likewise, questions on adaptive measures adopted by the respondents were included to further understand and correlate factors that influence their experience of the indoor environment. The quality of building materials used and the general comfort conditions and well-being of the residents living in the development were assessed by inquiring about the physical condition of the building (presence of dampness) and the maintenance and cleanliness regime of the surroundings.

Table 1: Selected questions from the householder questionnaire survey

<table>
<thead>
<tr>
<th>No.</th>
<th>Variables</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>About the household</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Duration of occupancy</td>
<td>Survey was done for households that had been occupied for a minimum of 5-6 months.</td>
</tr>
<tr>
<td>2</td>
<td>Number of residents in the house</td>
<td>Infants (≤ 3 years)</td>
</tr>
<tr>
<td><strong>Perceived indoor environment in summer &amp; winter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Indoor temperature</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>7</td>
<td>Air quality</td>
<td>stuffy</td>
</tr>
<tr>
<td>8</td>
<td>Air movement</td>
<td>draughty</td>
</tr>
<tr>
<td>9</td>
<td>Overall experience</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>11</td>
<td>Adaptive strategy during summer</td>
<td>Natural ventilation</td>
</tr>
<tr>
<td>12</td>
<td>Adaptive strategy during winter</td>
<td>yes</td>
</tr>
<tr>
<td>13</td>
<td>Artificial lighting required during the day</td>
<td>yes</td>
</tr>
<tr>
<td>14</td>
<td>Dampness in the house</td>
<td>yes</td>
</tr>
<tr>
<td>16</td>
<td>Causes of dampness</td>
<td>Leaking of pipes</td>
</tr>
<tr>
<td><strong>Maintenance and repair</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Regular maintenance of the common areas</td>
<td>yes</td>
</tr>
<tr>
<td>18</td>
<td>Experience with respect to the building materials used</td>
<td>Satisfactory experience</td>
</tr>
</tbody>
</table>

For easy comprehension the questionnaire was translated into the local language (Hindi) and the householder responses were later translated back to English for analysis. The survey was conducted by students (researchers) trained by the MaS-SHIP team, from a local educational institution. The students were trained through training workshop and mock surveys conducted by the MaS-SHIP team. A batch of 10 students took 4 days to complete the survey of 150 households.

Households were selected through random sampling and were generally suggestive of the availability of the members in the house as well as their eagerness to participate in the survey. While conducting the surveys, the responses were gathered from the available adult at home, and the feedback is assumed to be the general perception for that household. So each survey response represents a single dwelling unit.
Photographic survey

The researchers conducting the survey took digital pictures of the interiors of the dwellings and the surrounding areas (after seeking permission from the resident/s) to provide contextual data about the physical environment.

Researcher observations

The researchers also recorded their experience of conducting the survey and observations about the development, by completing two personal logs - one at the end of day one of the survey, and the second after completing the survey for the development. The information derived from the student logs generally helped to triangulate the findings from the questionnaire survey, and also at places provided additional feedback regarding various aspects of any particular surveyed development. Some of the conclusions made in this study were also derived from the students’ observations.

Overview of the case study

Following the Supreme Court’s order to relocate both polluted and non-polluted industries from the city of Delhi, over 16,000 industries shifted to the 760-hectare complex set up at Bawana Industrial area in North-West Delhi. The Bawana housing, developed by DSIIDC (Delhi State Industrial and Infrastructure Development Corporation Ltd.) was constructed as a part of the Rajiv Gandhi Housing scheme primarily to provide shelter for the industrial workers and other Economically Weaker Sections (EWS). Located at around 30km from the city centre, the development is a typical example of habitat relocation of residents living in informal settlements in the heart of the city to the outskirts.

The housing development is spread across 37 acres (~15 hectares) having a high density-about 300 dwelling units per hectare. A total of 4384 dwelling units are housed in a mix of 2, 3 and 4 storey exposed brick buildings with 4 dwelling units on each floor. Cluster planning was adopted, to provide organised open spaces and green areas in the form of courtyards. The carpet area of the dwelling units ranges between 263 sqft. to 311 sqft, with each DU comprising of two rooms, a separate WC and bathing space, and a covered balcony. In terms of household size, the survey revealed that majority of households had four members, although a significant number of dwellings had five or more members, making the living congested.

The housing complex was intended to be developed as an economical, environment friendly and energy efficient housing. It is one of the first social housing developments in India which was built using alternative materials and technologies. Table 2 provides details of building materials used in the project.

| Foundation | Single reamed pile foundation |
| Superstructure | Single brick load bearing wall using combination of modular Fal-G brick work & mechanised modular perforated bricks. flyash with cement mortars |
| | Precast Ferro cement in stairs, kitchen shelves |
| | Precast R.C. lintel & sunshade |
| Roof / Floor slab | Precast RC Plank and Joists and cast in-situ waist slab in RCC |
| Doors and windows | Second class Teak wood door window frames and flush door |
| | Grill in ventilators and windows |
Analysis and results

Perceived indoor environmental conditions

The survey revealed interesting findings about householder perception of their indoor environmental conditions (indoor temperature and air quality) in their homes during winter and summer. The number of householders perceiving indoor temperature as unsatisfactory during summer (n: 56) is about three times of that during winters (n: 20) (Figure 1). The tolerance of indoor temperatures is observed to be higher in winters with more number of residents reporting feeling satisfied (n: 32) as compared to that during summer (n: 19). A similar trend is observed in terms of perceived indoor air quality wherein 68 out of the 148 surveyed households, find their homes stuffy during summers, whereas in winters this number is reduced (25 out of 146), and majority of the residents (112 out of 146) perceived indoor air quality to be bearable, with a small number perceiving it as fresh during both summer and winter. In this study, bearable indoor air quality is assumed to correspond to a lesser stuffy house, an indoor condition which the residents have learnt to cope up with.

Despite the indoor air quality being perceived as poor, on inquiring about the indoor air movement, nearly 59% (87 out of 148) residents felt their homes were well-ventilated during summers. Owing to the relatively better indoor conditions experienced during winters, nearly 89% of the residents rated the overall experience as satisfactory (21%) or bearable (68%) during winter, as compared to the 67% residents who found the overall experience as satisfactory (12%) or bearable (55%) during summers. Consequently, the number of householders unsatisfied with the overall experience in winter, was nearly a third of that during the summer.

Deeper analysis of the survey responses for indoor environmental conditions was performed in order to assess the influence of the perception of indoor temperature and indoor air on the residents’ overall experience during summer and winter. For this, both crosstabular and nonparametric statistical analysis were used to correlate the householders’

![Figure 1: Householder survey results for perceived indoor environmental conditions in summer and winter](image-url)
response for perceived indoor temperature, air quality and movement with their overall experience during summer and winter. Table 3 shows the cross tabulation of householders’ responses for perceived indoor temperature, air quality and air movement with their overall experience during summer.

Table 3: Cross tabulation of householder responses on perception of indoor temperature, air quality and air movement with their corresponding response for overall experience during summer

<table>
<thead>
<tr>
<th>Overall experience in summer</th>
<th>Perceived indoor temperature in summer</th>
<th>Overall experience in winter</th>
<th>Perceived indoor temperature in winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsatisfactory</td>
<td>Bearable</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>45</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Bearable</td>
<td>4</td>
<td>64</td>
<td>5</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>0</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>Column total</td>
<td>49</td>
<td>81</td>
<td>18</td>
</tr>
</tbody>
</table>

Cross relating the householders’ responses about their perception of the indoor environmental conditions during summer (Table 3) revealed that an unsatisfactory perception of the indoor temperature and air quality had a direct impact on the residents’ overall experience of the indoor environment and resulted in an unsatisfactory overall experience. Of the 49 households reporting unsatisfactory overall experience 45 were also unsatisfied with the indoor temperatures and 43 perceived indoor air quality as stuffy. Similarly a bearable perception of the indoor temperature and indoor air quality lead to an overall bearable experience and is indicated by the fact that of the 81 households with bearable overall experience 64 perceived indoor temperature also as bearable and 54 perceived indoor air quality as bearable during summer. Interestingly for households with satisfactory overall experience during summer (n: 18) the number of households with perceived indoor air quality as bearable remained highest (n: 13), indicating towards the poor air quality of the interiors during summer.

The perception of indoor air movement seemed to have a slightly mixed effect on the residents’ overall experience of the indoor environment during summer. It was observed that of the 49 households reporting unsatisfactory overall experience equal number of households (n: 24) perceived indoor air movement as still and well-ventilated. Similarly, for the 81 households with bearable overall experience, though the number of residents perceiving well-ventilated indoors was highest (n: 49), as substantial number of households also perceived indoor air as still. Well ventilated indoors however seem to result in a satisfactory overall experience for some householders (14 out of 18) during summer.

Table 4: Cross tabulation of householders’ responses for their perception of indoor temperature, air quality and air movement with their corresponding response for overall experience during winter

<table>
<thead>
<tr>
<th>Overall experience in winter</th>
<th>Perceived indoor temperature in winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>12</td>
</tr>
</tbody>
</table>
The cross-tabulation analysis of the householders’ responses for indoor environmental conditions during winter (Table 4) revealed a higher and nearly equal number of households with bearable perception of both indoor temperature (n: 85) and air quality (n: 84) and this resulted in majority (n: 100) of households reporting bearable overall experience. Consequently, the number of households unsatisfied with their overall experience was found to be very less and for these residents, perception of indoor temperature seemed to have a relatively stronger effect. Of the 16 households reporting overall experience as unsatisfactory 12 perceived indoor temperatures also as unsatisfactory and only 9 perceived indoor air quality as stuffy. Similar to summer during winter too, of the 30 households reporting overall experience as satisfactory, 24 perceived indoor temperatures also as satisfactory and 22 households perceived indoor air quality as bearable. Indicating that the indoor air quality remains ‘just’ bearable inside these dwelling during both summer and winter. Unlike summer, in winter of the 100 households with bearable overall experience, the number of households with still indoor air was found to be highest (n: 43). Indicating residents’ preference of still indoor air during winter. Of the 30 households with satisfactory overall experience during winters two third (n: 20) households perceived indoor air movement to be well-ventilated.

The residents of the surveyed dwellings were found to rely more on active cooling measures in summer as compared to more passive adaptive methods in winters. The survey revealed that apart from making use of natural ventilation, 130 out of the 149 surveyed households used ceiling fans, and a substantial number of these households combined the use of ceiling fans with evaporative cooling measures such as use of desert coolers to enhance indoor comfort conditions during summer. The relatively poor perception of the indoor environmental conditions during summer however indicates the inability of the dwelling units to provide comfortable indoor environment in the summer (in absence of air-conditioning). In winter, majority residents reported resorting to warm clothing and blankets and use of fire (in the form of bon-fire outside the house). Electric heaters were used in a very few households, due to the high electricity bills associated with their use.

Furthermore, statistical tests were applied to assess the strength of association among the factors influencing residents’ perception of indoor conditions. Spearman’s correlation coefficient (r_s), also called Spearman’s rho, is used to establish the correlation between the rankings of two variables. The value of r_s ranges from -1 to +1, the closer r_s is to ±1 the stronger the monotonic relation between the two variables. Kendall’s Tau-b (τ_b) correlation coefficient, also considered as an alternate to the Spearman’s correlation is a nonparametric measure of the strength and direction of association that exists between two ordinal variables.
Both statistical tests when applied to the householder survey responses for indoor environmental conditions show similar results. The Spearman’s correlation coefficient ($r_s$) values of 0.803 and 0.712 (Table 5) for overall experience vs perceived indoor temperatures in summer and winter respectively, reveal indoor temperature as a noteworthy factor in influencing the householders’ perception of the overall indoor environment during both summer and winter. Whereas the $r_s$ values of overall experience vs perceived indoor air quality shows strong correlation between the two variables in summer, but shows weak correlation in winter. Correlation coefficient values for overall experience vs perceived indoor air movement indicate weak correlation between the two variables, during summer and winter.

Table 5: Spearman's correlation coefficient values for householder survey responses for perceived indoor environment

<table>
<thead>
<tr>
<th></th>
<th>Spearman's correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall experience in summer</td>
<td></td>
</tr>
<tr>
<td>vs Indoor temperature</td>
<td>0.803</td>
</tr>
<tr>
<td>vs Air quality</td>
<td>0.616</td>
</tr>
<tr>
<td>vs Air movement</td>
<td>0.175</td>
</tr>
<tr>
<td>Overall experience in winter</td>
<td></td>
</tr>
<tr>
<td>vs Indoor temperature</td>
<td>0.712</td>
</tr>
<tr>
<td>vs Air quality</td>
<td>0.406</td>
</tr>
<tr>
<td>vs Air movement</td>
<td>0.322</td>
</tr>
</tbody>
</table>

**Daylighting**

The quality of indoor lighting was accessed by asking the residents if they needed to use artificial lighting during the day. Nearly one third (57 out of 149) of the surveyed households reported that they need to use artificial lighting during the day. Though the survey did not prompt the residents to provide reasons for their response, a few observations made by the researchers reveal either the absence of residents at home during the day; or availability of adequate diffused light to carry out their tasks. It was also observed that flats on the upper floors generally do not require artificial lighting during the day (Figure 2&3).

![Figure 2: Interior view of a room in a DU](image1)

![Figure 3: Interior view of kitchen space](image2)

**Experience with the building materials and technology**

The study also focused on visually analysing the quality of construction and building materials used and sought the residents’ perception of it through the survey questionnaire. During the interview the researcher inquired about the presence of dampness in that particular dwelling, its specific location and then prompted the respondents to choose one or multiple responses from the given options (Table 1, no. 16), as to what they perceived the cause for it. Since the

1 Guide to determine the strength of correlation for absolute value of $r_s$

0.00-0.19 “very weak”; 0.20-.39 “weak”; 0.40-0.59 “moderate”; 0.60-0.79 “strong”; 0.80-1.0 “very strong”
housing development was intended to be low-cost and energy efficient, the selection of building materials and technologies was primarily based on their cost effectiveness and also environmental friendly factors. The use of modular Fal-G brick work and mechanised modular perforated bricks for external walls resulted in cost saving by eliminating the need for external plaster. The current state of the dwellings however revealed the poor quality of construction workmanship and materials in the form of dampness inside many surveyed households. Of the 149 surveyed households, about 86 households reported the presence of dampness inside their dwelling, in the wet areas (kitchen and/or toilet walls), and hence attributed it to the leaking of pipes (poor quality of plumbing works) and/or building materials not being water resistant (Figure 4).

As shown in previous research that physical characteristics of low cost housing (such as quality of the interiors and the surroundings, cleanliness, maintenance and location) significantly affect residents’ perception (Mulliner et al., 2013), similar findings were revealed regarding householder experience with the building materials used in the dwellings. The flexibility of being able to adapt their dwelling as per one’s own day to day needs and aspirations is an elementary need of every human. The survey revealed ‘Nail-ability ‘i.e. the suitability [of a wall] for being nailed, as a main concern among majority of the residents (Figure 5). The choice of materials and the quality of construction of these houses, did not allow residents to make basic alterations to the interiors, like hanging a piece of art or a shelf to the walls, or adding or changing an electrical point. Residents also expressed their concern regarding the access to the plumbing pipes which poses limitations in carrying out any repair works. Some of the residents also voiced their concern on the aesthetics of the buildings related to architectural design and/or external/internal finishes.

**Maintenance and up-keep**

The researchers (students) also inquired from the householders about the maintenance and repair mechanisms in place for the development and if they paid any charges for maintaining the common areas of the building and its surroundings. Majority of the householders expressed their dissatisfaction regarding the lack of maintenance and cleanliness of the development and were unaware of any committee that might have been setup or of a requirement of a regular maintenance fee. The open courtyards meant to promote community interaction were seen filled with garbage and stagnant water in the open drains. A few residents reported cleaning the immediate surroundings of their dwellings, but the development at large lacks cleanliness and hygiene (Figure 6 & 7).
Location and accessibility to the basic public facilities

The Bawana housing development is located on the outskirts of Delhi, approximately 30 km away from the city centre. At the time of the survey, it was observed that most of the original owners of these dwellings had moved to a different location and rented out their houses in this development. Out of the 149 surveyed households, 119 houses were occupied on rent. A majority of them paid a monthly rent less than half of their monthly income. An almost similar number of households also reported spending half of their income in house rent every month.

During the survey however, majority of the residents’ reported having convenient proximity to employment or other basic amenities like hospitals and schools. For most residents the place of work was up to 20 minutes’ walking distance from their homes (Table 6). A substantial number of people also have vehicles of their own to commute to work and other places. Though a large number (n: 93) of residents reported having access to public transport to commute to hospitals there were substantial numbers (n: 38) of households reporting availability of conveyance as an issue for travelling to hospitals. Of the 149 surveyed households, 90 had school going children. Majority of them used school bus or had their schools at walking distance from the development.

<table>
<thead>
<tr>
<th>Survey questions pertaining to location of the development</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convenient proximity to employment (n=149)</td>
<td>Yes: 113</td>
</tr>
<tr>
<td>Convenient proximity to school/hospital (n=149)</td>
<td>Yes: 128</td>
</tr>
<tr>
<td>Travel time (in minutes)</td>
<td>&gt;20: 39</td>
</tr>
<tr>
<td>To work (n=149)</td>
<td>Yes: 94</td>
</tr>
<tr>
<td>To school (n=90)</td>
<td>Yes: 67</td>
</tr>
</tbody>
</table>

Table 6: Householder responses related to location of the development

Discussion

The Bawana housing development was constructed with the intention to rehabilitate the industry workers and people from EWS in a settlement with better living conditions. Although the building materials used in the project were low cost and environment friendly, the householder survey revealed that indoor comfort was perceived to be (just) ‘bearable’ during
summer and winter. Only 12% of respondents rated their indoor conditions as ‘satisfactory’ in summer, whereas nearly the same proportion (11%) rated it as ‘unsatisfactory’ in the winter. This indicated the inability of the dwelling units to provide comfortable indoor environment in the summer (in absence of air-conditioning). However in winter, higher levels of adaptation occurs wherein residents resort to warm clothing and blankets, along with a reduced heat loss due to small size/exposure of the dwelling units. Air inside dwellings was perceived to be still by one-third of residents, though still air was desirable in winters. Through multiple statistical analyses, a greater correlation between the perceived indoor temperature and overall experience of the indoor environment during both winter and summers is observed. While this may differ in reality which will require a next level analysis of quantified indoor temperatures vs the comfort temperature, this could also be attributed to the design of the questionnaire survey. Considering the fact that the occupants were asked of their perception of indoor temperature, air quality, and air movement, temperature is often a more palpable parameter for the people to realise as a factor of comfort or discomfort.

The survey also revealed factors that determine the acceptability of building materials from the householders’ perspective. The factory finished exposed brick work used for the walls may have helped to reduce the initial construction cost, but nail-ability of the walls emerged as a major concern for the residents, since the wall materials did not allow residents the flexibility of making basic alterations to the interiors. It was also realised that poor quality of plumbing and workmanship was widespread in the development. Presence of dampness was found in many dwellings, with residents expressing dissatisfaction with the inaccessibility of the pipe work and poor water proofing. It is vital that construction quality is kept high in such projects to reduce maintenance costs in the future.

There appears to be a lack of maintenance regime for the upkeep of the common areas. The survey revealed that unoccupied dwelling units had become dumping yards with garbage spill-over in the streets. An institutional system for regular maintenance must be put in place to ensure the health of the residents’. At the time of the survey, about 80% of the surveyed households were found to have tenants. The residents also expressed their dissatisfaction about the availability of job opportunities within accessible distances from the development. It was evident that due to the location of the development, most of the residents were forced to relocate back in order to retain their jobs in the city.

**Conclusion**

This study has revealed for the first time, resident perception and experiences of inhabiting a sustainable social housing development. The findings reveal that the quality of indoor environment, quality of the interiors, the maintenance and up-keep of the surroundings and availability of job opportunities at convenient vicinity are important factors in determining the level of ‘satisfaction’ of the residents.

With the Government of India’s ambitious plan to construct 12 million such social housing units by the year 2022, there is an increasing stress on the use of alternative and sustainable building materials and technologies in order to reduce the environmental impact of housing construction at such a massive scale. This study provides important new evidence based on residents’ perception of living in a ‘sustainable’ social housing development. It is evident that the use of sustainable materials alone is not sufficient for a social housing to be sustainable; construction quality of the building envelope is vital for achieving the expected performance. Moreover appropriate passive design strategies (based on the climatic zone)
must be incorporated in the design in order to provide thermally comfortable indoor environment during both summer and winter. The ability to make changes in dwellings matters to residents and should be considered in the form of design for adaptation. Maintenance and cleanliness of the common areas and surroundings are important not only for the health and well-being of the residents, but also to ensure the appropriate use of passive design features such as opening of windows. Ideally a low cost but effective maintenance regime should be put in place. These factors need to be carefully considered in the planning, design, construction and operation stages, if these social housing developments are to be truly sustainable and liveable for the residents.

Acknowledgment

We are grateful to UN Environment for sponsoring the Mainstreaming sustainable social housing in India project (MaS-SHIP). MaS-SHIP is a research initiative by the Low Carbon Building Research Group at Oxford Brookes University, The Energy and Resources Institute (TERI), Development Alternatives and UN-Habitat. It is supported by the Sustainable Buildings and Construction Programme of the 10-Year Framework of Programmes on Sustainable Consumption and Production (10-YFP). The authors are thankful to the students of Vastu Kala Academy for conducting the surveys and also to residents of the case study development for their responses.

References


Abstract: Accident rates of construction industry in India is highest among all other industries, affecting macro to micro level projects and needs a comprehensive tools to prevent accidents to construction workers among all levels of projects. As like other countries, different initiatives were launched by Indian government to improve safety on Indian construction workplace, but still face poor safety outcomes. According to experts’ survey, it was found that design has the major impact on health and safety in construction projects. From researchers’ point of view, it was deduced that design can help to prevent risks and hazards associated with construction projects. Prevention through design (PtD) is an occupational health and safety approach which prevents or reduces the hazards in construction workplace by addressing workers safety in the design phase of the projects. The purpose of this study was to develop a framework for preventing accidents to workers among construction industry in India. Through literature survey, accidents data was determined for the desired framework and by reviewing literature, a comprehensive tool to prevent accidents to construction workers was determined. It can be expected that the developed framework from this study will be benefit to Indian construction stakeholders for improving their own safety performance. Further, it was recommended that PtD techniques can also be in-built into the Indian health and safety initiatives plans to improve safety performance of the construction industry.

Keywords: Accidents, Indian construction, Workers safety, design-based framework

Introduction

Construction industry has recorded a poor safety performance all over the world. Globally, 60000 deaths occur in construction industry per year compared to other industries like transportation, manufacturing and so on (Fewings, 2013). In 2006, 21% of fatalities were accounted in construction industry of United States of America (Forbes and Ahmed 2011). Construction sector in Germany is accountable for 20% of work related injuries (Arndt et al., 2005). While in 2006, fatality rate in Singapore construction industry recorded 39% of total occupational fatalities (Ling et al., 2008). Construction accident rate in Australia is 9.2 per 100,000 workers and still lot of construction workers are being injured and killed every year in construction. In 2000, 84 fatal accidents were recorded in UK construction industry (Cameron and Duff 2002).

In India, construction is the second leading sector next to agriculture but accident statistics in construction sector is not frequently and accurately reported. Therefore, accident statistics in Indian construction industry is not easily available (Hämäläinen, 2010). It is predictable that construction industry in India will account for huge amount of injuries and fatal incidents due to dynamic environment and enormous number of stakeholder’s involvement (Patel and Jha 2016). Generally, if any accident occurs in construction workplace then it means that there is a severe safety issue which need to be addressed (Hoyle, 2009). Accidents in construction workplace lead to indirect cost, workers compensation, medical treatment and productivity losses apart from effects on human
illness (Abdelhamid et al., 2002 and Schafer et al., 2008). Accidents also directs to emotional and mental impacts to co-workers, families and friends of the victims (De Saram and Tang 2005).

Thus, safety in construction industry becomes a serious issue among practitioners, academics, the public and the government (Hoyle, 2009). As like other countries, different initiatives were launched by Indian government to improve safety on Indian construction workplace (Shyam pingle, 2012). But still accidents occur in construction industry which results in fatalities to many workers (Bashir, 2011). Therefore, preventing accidents on construction workplace has become a great challenge for stakeholders which need a new approach.

Prevention through Design (PtD) is an occupational health and safety (OHS) approach of preventing hazards in workplaces during design stage of a project that affects people in the occupational environment to eliminate or mitigate occupational-related injuries, illnesses, fatalities, and hazardous exposures. PtD is achieved by the application of risks and hazards mitigation/elimination technique in the design of procedures, tools, equipments and work facilities. The goal of PtD is to “design out” possible risks and hazards at the starting stages of a project (Atila Ertas, 2010). Ultimately money can be saved and workers can be protected if the hazards are eliminated or minimized during the design process (Gambatese, 2008).

Usually, safety is not referred by the designers in design of construction projects in many countries. Gambatese et al. (1997), marked that safety in construction industry will be improved if the designers are reactive to safety outcomes for their design decisions. Designers in construction projects are not conscious of their impact on safety, as they do not have adequate experience and knowledge for playing a role in it (Gambatese et al., 1997). Improvement in productivity and reduction in environmental damage can be achieved if the risks are identified and eliminated at the design stage of the construction projects (Hinze and Wiegand 1992). In order to minimize the likelihood of event during construction process, certain measures must be carried out at the beginning of the design phase of project (Yang and Li 2015).

Hence, from the researchers’ point of view, it can be deduced that design can help to prevent risks and hazards associated with construction projects. However, there is no such study on PtD is available in Indian construction industry. Therefore, this study was carried out to answer the subsequent basic questions: 1. How do PtD associate with safety at construction workplace? 2. How could PtD be used to improve safety at Indian construction workplace?. To address these research questions, the aim was set to investigate the relationship between design and safety issues and the mechanism by which PtD could be used to improve safety in Indian construction workplaces. To achieve this aim, the following research objectives were followed. 1. To identify the various causes of construction accidents and investigate how they are linked with design through critical literature study. 2. To develop a framework to improve safety issues in Indian construction industry using PtD approach.

**Background**

*Health and safety in Indian construction workplace*

Labour force of construction in India is 7.5% of the global labour force and it contributes to 16.4% of global fatalities (Kulkarni, 2007). According to International Labour Organization
(ILO) survey, the accident rate of Indian construction is high among global construction sector showing 165 per 1,000 labours are injured during work (Patel and Jha 2016). According to 11th Five-Year Plan (2007-12), Indian construction industry accounts for about 11% of all occupational injuries (Patel and Jha 2016). In today’s Indian construction scenario, safety is becoming one of the significant issues because of its increasing number of accidents/incidents.

**Accidents in construction workplace**

According to international labour organization (ILO), accident is defined as an unexpected event and accidental incidence, occurring due to work that results in injury, disease or death to labours (Shalini, 2008). Health and Safety Executive (HSE) defined accident as any unexpected occurrence that results in deaths or injury to people, and loss to working environment including property, equipments and materials (Hughes and Ferrett 2008). Construction, demolition and renovation of buildings include repetitive activities which are done with different equipment, machines and techniques where workers are exposed to different hazards and risks (Hughes and Ferrett 2008). The activities are associated with labour due to manual handling, vibration, dust, noise and environment that effect on workers’ health, even if the working environment have enhanced in many developed countries (Arndt et al., 2005). Change in working environments, frequent changes in location, materials variation, nature of works, weather effect, continuous movement and weather effects are other factors associated with workplace (Perttula et al., 2003). These factors have resulted in accidents through slips and trips, struck by objects, fall from height, straining, cuts, being caught in/between, tumbling, electric shocks, being hit by falling materials, over exertion and electrocution (Perttula et al., 2003 and Ling et al., 2008).

**Causes of accidents in construction industry**

Different disciplines were suggesting different root causes for accidents by developing a number of accident causation modes over past decades (Li and Poon 2008). To identify the different causes of accidents on construction workplace, numerous studies have been carried out, in which observations from some studies on certain causes of accidents are similar and some differ completely. According to (Sawacha et al., 1999), accidents occur due to human or judgment error, poor safety training, excessive stress and unsafe behavior. Further, Wolf and Brick (1996) suggested that accidents occur due to poor site supervision and poor coordination of workers. The study by FISCA (2006) views on poor work methods, poor planning and control, lack of site awareness, poor communication and organizational pressure as one of the causes of poor safety performance. Suraji et al. (2001) pointed out site congestion as one of the accident causes in construction industry. According to Kletz (1993), accidents occur due to physical and mental disability of human. Mitropoulos et al. (2005) suggest that site hazards are the main contributing factor for causes of accidents in construction industry.

An accident lead to indirect costs gained through medical treatment, workers compensation and so on and also affects the productivity of business (Abdelhamid et al., 2003 and Schafer et al., 2008). In addition, an accident directs to psychological impacts to workers involved (De Saram and Tang 2005). Therefore, health and safety problems become a serious issue in construction sector among the practitioners, academics, the government and the public in common (Hoyle, 2009). Many developed and developing countries
launched different initiatives to improve the performance of poor safety on construction workplace (Suraji et al., 2001; FISCA 2006; Gambatese et al., 2008 and Shyam pingle 2012).

**Influence of design in construction accidents**

Safety outcomes in construction are influenced both directly and indirectly by design professionals which includes the procurement system selection, specification of materials, construction process sequencing, etc. (Trethewy and Atkinson 2003). 60% of the accidents surveyed by the European Foundation (1991) could have been reduced, eliminated or avoided during design phase of the project. 50% of workers thought design contributes the major role on safety in South African construction (Smallwood, 2008). Kamardeen (2013) analyzed the construction accidents from seven diverse regions and found that design is the reason for 35% of overall accidents. Gibb et al. (2004) found that 47% of the reviewed 100 construction accidents could reduce the likelihood of the accident by permanent design. Australia National Coroner’s Information System identified that design is the major cause for 37% of 210 construction site deaths (Driscoll et al., 2008). More research is required to study about the relationship among construction accidents and design (Gibb et al., 2004).

**Prevention through Design (PtD)**

The prevention initiative in the design stage was initially mentioned in the National Safety Council’s prevention manual in 1955 (Driscoll et al., 2008). A definition of Prevention through design is “Addressing work-related health and safety requirements in the design stage to reduce or avoid risks and hazards linked with maintenance, manufacture, construction, use, equipments and materials” (Atila Ertas, 2010). But due to the pending of Construction Industry Institute sponsor, the application of PtD was not begun in US (Gambatese et al., 1997). Soon after, the PtD concept was recognized slowly and became functional in the USA (Lin Yang et al., 2015). In 2007, National Institute of Occupation Health and Safety (NIOSH) called key industries that include Occupational Health and Safety Administration (OSHA), Center to Protect Worker’s Rights (CPWR), Kaiser Permanente, American Industrial Hygiene Association (AIHA), Regenstrief Center for Healthcare Engineering and Mutual, National Safety Council (NSC), American Society of Safety Engineers (ASSE) began a national initiative called “Prevention through design” to underline risk and hazard prevention or reduction in design phase of equipment’s, work process and tools (Deborah and Young-Corbett 2014). Thereafter, many industries in US begin supporting the PtD concept and actively support them as well.

In July 2007, the initial PtD workshop was conducted at Washington which intends to prevent or eliminate occupational risks and controlling hazards at the design phase of the project (Lin Yang et al., 2015). Around 225 members were participated from different disciplines and the scientific notes authored by PtD specialists was printed as a special edition in Journal of Safety Research in 2008 (Lin Yang et al., 2015). National Initiative on PtD is framed by four functional areas which include Research, Practice, Education and Policy to promote and implement it (Lin Yang et al., 2015).

The concept of PtD is shared of different disciplined that comprises mining, agriculture, forestry and fishing, healthcare, transportation, construction, warehousing, social assistance and manufacturing. The PtD goal is to minimize or avoid work-related illness and injuries by integrating the PtD process in early phase of project life cycle (Atila Ertas, 2010). Figure 1 represents the PtD processes that begins with describing the tasks and then identify and
analyze the risks and hazards linked with the tasks and launching the feasible control measures.

PtD in Construction

The phrase “design” in construction is usually used in the process of making the final product to be created: the structure, infrastructure, or facility element. But, PtD has a wide range of description and applies to the equipment, work processes, materials and all tools design that is engaged in the process of construction. Thus, hazard minimization can be achieved by means of such changes in equipment and tool selection, management in work process, material selection and designing of facility. Lot of tasks completed till now in PtD in construction highlighted the risk minimization in the occupational health and safety field.

The US is somewhat behind compared to all other developed countries in the dispersal of PtD concepts and acceptance of PtD approaches among construction industry (Toole and Gambatese 2008). Awareness on PtD concepts is not wide spread in Indian construction industry. However, the PtD concepts were broadly accepted in Australia and European Union. These countries were well experienced to handle the barriers to the PtD dispersion and lessons can be learned from them. Due to controversial nature of sector environment, liability could be a huge barrier for accepting PtD in US (Toole 2005). Four key features of PtD were identified to highlight as the construction industry proceed towards accepting a PtD approach (Toole and Gambatese 2008). These four features were enlarged prefabrication, enlarged construction engineering application, minimized use of hazardous materials and improved spatial consideration. Many of the organizations those participated the PtD National initiative workshop in 2007 have been practical in examining and executing PtD plan, however that firm broad dispersion of PtD novelty is documented poorly so that a best practices is required. This study thus aims to develop a framework by integrating PtD process in generic construction design process which can be followed in Indian construction projects to minimize or avoid hazards and risks in the workplace.

Development of a framework

The process of PtD is integrating the health and safety concept into the construction project management. PtD helps in addressing health and safety of construction workers in design stage to avoid or reduce the hazards linked with the project tasks. PtD main goal is to
minimize the occupational illness or injuries by integrating PtD process in whole stages of project design process (Deborah and Young-Corbett 2014). Figure 2 represents the numerous stages in the construction design process and how PtD is integrated into these stages. PtD process also shows the phases involved in it.

Figure 2. An integration of PtD process with generic design process of construction projects

The design process of construction project starts with defining the requirements of clients. The requirements of clients for the projects are illustrated in this stage by a design team. Here, the design team will intimately work with clients to decide the functional requirements of the projects. This phase will stand as a basis for forthcoming phases.

Project solutions are identified in concept design phase, by which the most favorable approach can be chosen. The selected concept feasibility will be accomplished to make sure that the concept is practicable both precisely and within cost limits. The concept design PtD phase objective is to evaluate the feasible concept by which the safety and health of construction labours can be secured from hazards. The team members must have good experience and skills in decision-making who involves in feasibility phase of design process. In this analysis, concept design alternatives and project workplace environment will be considered. PtD ideas are pointed for a favored concept design, including: types of temporary structures, construction materials and methods, types of equipment’s, etc.

The gap between concept design phase and detailed design phase will be filled by preliminary design phase. The developed concept is further defined in preliminary design phase. The best solution will be evaluated in the preliminary design phase if more than one concept is involved in concept design phase. The concept development must be incremental than total reassessment in preliminary design phase. The overall system configuration
includes schematic and drawings, diagram, layouts, and other engineering configurations which are defined during preliminary design stage. Here in preliminary design, first an inspection has to be taken on to confirm that concept design PtD ideas have been absorbed in sensibly. Then, hazard investigation will progress from a facility to system level analysis. The study of draft designs will recognize and examine work occupations to be involved in the project. For example, works at heights, crane use, deep excavation, confined work spaces, manual handling, etc. PtD ideas will be set for controlling risk through preliminary design stage, once work occupations and hazards in the project has been identified.

The project design will be prepared further in detailed with a condition of each segment (structural, architectural and mechanical, etc.), once the preliminary design is placed. Detailed design examines the specifications of specific elements to discover hazards caused by design decisions. The risk analysis phase will fix which of the hazards are removable and to be managed on workplace by design reviews. Then, reports will be made for design reviews based on PtD suggestion.

**Stakeholders’ knowledge to perform PtD**

Designers must have knowledge of construction environments, in order to implement PtD. Each design generates a construction environment, which has the guidelines of hazard posed by the design choice. The construction environment can be framed of five components, including: workplace settings – convenience and space, workplace condition, road condition; job settings – job location and temporary facilities to be build; nature and type materials used; nature and type of equipment used; and skill of labour. A one or group of components can cause accident in construction. Hence, a what-if analysis must be performed for all conceivable design decisions for a construction project to take account of their construction environment and make safe design choices. Here, skill gap of designers is the critical challenge. Since designers do not work on construction workplace and mainly skilled in design principles, they usually have only limited information of construction processes and environments triggered by their designs. To perform PtD analysis, complete information of construction practices, risk assessment/management and occupational health and safety is essential.

**Concluding remarks**

Safety is becoming one of the most important issues in today’s Indian construction scenario, because of its increasing number of accidents/incidents. Promoters of design for construction promise that PtD technique will enhance the safety and productivity of the projects. In this paper, causes of construction accidents and PtD concepts were reviewed through literature. Based on the findings, a framework was developed by integrating PtD process in generic construction design process which can be followed in Indian construction projects to minimize or avoid hazards and risks in the workplace. This framework could be used to guide the Indian construction practitioners in using PtD as a strategy to promote safety in construction workplaces. Also, PtD techniques can be in-built into the Indian health and safety initiatives plans to improve safety performance of the construction industry.

**References**


Optimised external and internal constructions in buildings in hot and dry climates to support thermal comfort without air conditioning

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Abstract: In hot and dry climates, it is challenging to design a passive building – optimised to reach thermal comfort by using only passive systems - in which indoor temperatures are during daily peaks always below outdoor temperatures. This investigation seeks to study the correlations between the physical attributes of different external and internal constructions materials to understand which ones could be more suitable for being used as building materials within the context of Cairo, Egypt. Based on findings on a previous optimized room (including different ventilation strategies, size and arrangement of windows, external and internal shading systems), a digital model of a standard room was built up in the Energy Plus based software Primero Comfort, and different scenarios created out of a palette of external and internal constructions and materials were simulated. The results were then compared by using a self-developed “indicator of potential of passive optimisation”. The findings show that materials with a smaller U-Value perform better than the others. Interestingly, by looking more into detail at further correlations with other physical quantities, it is observable that materials and constructions with a high U-Value (>2.5) and a low TAD (Temperature Amplitude Damping <10) perform particularly poor, because of a strong transfer of solar radiation through external constructions. In conclusion, recommendations for the optimisation procedure, as well as for a selection for building materials and constructions used in practice that perform well in hot and dry climates are made.

Keywords: Thermal Comfort, Indicators for Passive Optimization of Buildings, Temperature-Amplitude-Damping, Hot and Dry Climates, Room Simulation

Introduction

This paper provides an insight into the recent researches within the REAP¹ Research Group of the Hafencity University Hamburg that deals with energy consumption and end user’s thermal comfort in residential and office buildings in different climatic zones.

The results presented in the following pages build up on the research presented at the Cities and Climate Conference in 2017 (Potsdam, Germany). While the first publication deals with and tests different passive optimisation strategies to achieve a better indoor thermal comfort (see Dietrich & Vignola, 2018), as well as an energy efficient design (briefly summarised in the Methodology chapter), this paper investigates into depth the physical characteristics of the building constructions used for the external and internal walls, as well as ceiling and floor. Furthermore, it contributes to understand what attributes are relevant when choosing a construction material to be used in a dry and hot climate context.

The city this research focus on is Cairo, Egypt. While the biggest African metropolis is challenged by providing adequate living conditions and housing to its growing population, as well as providing energy supply without interruptions, the central government has not been able yet to give any incentives for specific programs on building energy-saving measures –

¹ Resource Efficiency in Architecture and Planning
be it active or passive measures - and, even as more and more scholars are getting acquainted with this kind of research, very little has been published so far on this matter, and most of it deals on energy consumption only, or on the outdoor comfort at the urban scale (Kraas et al, 2016; Horwood, 2011; ARE, 2015; Attia & Carlucci, 2015; Fahmy & Sharples, 2009; Fahmi, Sharples & Eltrapolsi, 2009).

The aim of this paper is to present a methodology that could help planners and architects to optimise the design of buildings by using passive adaptive strategies according to the local climate; this to achieve end user’s thermal comfort, while reducing the energy demand for cooling, heating, ventilation and artificial light. Furthermore, it aims to be of help in the decision-making process of choosing the appropriate construction materials depending on its physical characteristics and the impact to this can have to end user’s thermal comfort and energy consumption.

Methodology and Definitions

The central part of the outcomes was obtained by simulating and optimising a digital model of a room built up in Primero Comfort (Primero, 2018). Consequently, the results of the simulations were extrapolated in a calculation sheet, where it has been possible to compare them and to look for possible correlations.

Indicator for Potential of Passive Optimisation and Optimisation Strategy

In hot and dry climates, it is challenging to design a passive building – optimised to reach thermal comfort by using only passive systems - in which during the daily peaks operative indoor temperature ($Top$) is always below outdoor temperature ($Te$) and as often as possible also below the wished comfort temperature $T\text{comf}$. For the assessment of the quality of a passive optimization a new indicator $Topt$ was developed by the authors. $Topt$ is based on the fact that, unless the building has a high thermal storage mass and the cooling of $Te$ is possible thanks to night cooling and natural ventilation, the indoor temperature ($T\text{comf}$) will never be below outdoor temperature ($Te$). That’s why the indicator counts (as shown in the Figure 1) exceeding hours $Topt>T\text{comf}$ only in case of insufficient passive optimization - if the indoor temperature ($Top$) exceeds outdoor temperature ($Te$). $Topt$ is determined at all hours of use and summed up to a yearly value in Kh. To be able to compare models of rooms with different uses, the weighted indicator $Toptw$ was used; it

![Figure 1. Visualisation of indicator $Topt$ (potential of passive optimisation). The black areas (a) indicate the situation in which $Top$ and $Te$ are above $T\text{comf}$, and $Top$ is above $Te$ ($Top>T\text{comf}; Te>T\text{comf}; Top>Te$). The grey areas (b) indicate when $Top$ is above $T\text{comf}$ and $Te$ is below $T\text{comf}$ ($Top>T\text{comf}; Te<T\text{comf}$). (Dietrich and Vignola, 2018)]
divides $Topt$ by the number of hours that the room is used (6935, see subchapter “Digital Room Models”), and generates a yearly average (in Kelvin) in which the room is overheated. Because to keep comfort as a rule of thumb 1 degree difference between Top and $Te$ should not be exceeded, the results exceeding 1 K by the indicator $Toptw$ or 6935 K by $Topt$ are considered to be an opportunity for optimizing further. To be underlined, is the fact that the 1 K is a yearly average, and times in which a higher temperature difference are possible. Despite of that, the results give a good first impression of the potential for optimisation.

**Temperature-Amplitude-Damping as Indicator for the Dynamical Behaviour of External Constructions**

A construction separates the interior of a building from the exterior. If the temperatures $Te$ and $Ti$ are not identical a heat flux is caused through the construction that tries to balance both temperatures. In a hot and dry context, especially during daytime when $Te$ is higher than $Topt$, it is expected to have the heat flux shifting from the outside to the inside of the construction. By increasing the thickness of a construction, its resistance to the heat flux can be increased. However, even though resistance is the basis for heat flow calculation, it is based on steady state assumption. Because buildings are subject to change in temperatures and radiation regime, the heat flows are dynamic, and vary periodically.

The dynamical behaviour of constructions is described in the standard ISO 13786 (2017) and the main indicators used for constructions are *decrement factor* and *decrement delay* (time shift). The *decrement delay* (expressed in hours), expresses the time difference in inner temperature peak with respect to outdoor peak. The *decrement factor* is the ratio between the indoor temperature amplitude and the outdoor temperature, and express “the capacity of an element to reduce the temperature swings in a space” (La Roche, Quiros, Bravo, Gonzalez, Machado; 2001).

Furthermore, another indicator used in this research is the Temperature-Amplitude-Damping (also called admittance, see Hens, 2017), which expresses the ratio between the amplitudes of $Te$ and $Tsi$ (Indoor Surface Temperature). A low Temperature-Amplitude-Damping (TAD) means that heat absorbed on the external surface of a construction (especially by absorbed solar radiation) can transfer easily through the construction, heating up the construction first and thus the room.

**Thermal Storage Mass of a Construction as Indicator for Potential of Reducing Indoor Peaks in Temperature**

All building constructions have a certain heat storage capacity that let them absorb the heat during the heating process, and release it during the cooling process. In case the diurnal outdoor temperature difference is more than 8 K, a high heat storage capacity will help to reduce the amplitude of variation as well as the indoor temperature peak (La Roche et al; 2001). In the subchapter “Storage Capacity of Different Room Elements” results gained by the calculation of materials with different storage mass are discussed.

To estimate the storage mass of constructions, the calculations have been derived from the decrement delay calculated with the standard ISO 13786 (2017). First the velocity as well as the active thickness ($d$) of material that is going to be “activated” in 2 hours have been computed. Then, by multiplying the heat capacity ($c$) by the density of the material ($\rho$) and the active thickness ($d$), the thermal storage mass of the construction has been finalized and used as a basis for discussion.
**Optimization Strategy**

The optimisation strategy used, and therefore the simulation procedure, follows the basic rules that are required when building in this kind of climate: while in the first step the priority is given to the reduction of solar heat gains (by dimensioning the windows, shading windows and façade, and adding a window screening with the optimal grade of transmissivity), in the following ones priority is given to remove the heat (different ventilation strategies as well as by optimising the building envelope). In the following pages the focus is given to the last part of the process – the choice of building materials— and the criteria that should be considered when optimising a standard bedroom with two windows and with ventilation possible only through the façade (no cross ventilation).

**Digital Room Models**

Primero Comfort is an EnergyPlus based room simulation software that allows, thanks to the use of the input of hourly weather data (e.g. from the EnergyPlus database), and thanks to the different parameters that can be adjusted at any time to deliver both the assessment of the internal comfort of a room, as well as the energy balance (heat flows, ventilation, cooling, etc.). The parameters that can be adjusted include different ventilation strategies,
room usages, size and arrangement of windows, external and internal shading systems, a palette of constructions and materials, etc. (Primero Comfort, 2018). As shown in Figure 2, the models have an area of 15 m\(^2\) and a height of 3 m. The size of the room corresponds well to a typical standard room in an apartment. The orientation of the main façade faces South. To make effects of external wall construction visible as much as possible, it was assumed that the room is in the corner of the building. The room is thus composed by two internal walls (facing North and East) and two external facades (facing South and West). The window size corresponds to minimal expectation regarding daylight access and view out of the window. The size of overhang as well as the transparency of the screen are results of a preliminary optimization of the room (Dietrich & Vignola, 2018). To make the effects that natural ventilation has on the external constructions as visible as possible, the worst case – no cross ventilation / ventilation only through one façade - was assumed. The room is assumed as a bedroom with a daily 19 hours of usage (6 am - midnight with internal heat gains [total of 6935 hours]; midnight - 6 am no artificial light, no heat gains – people are assumed to be sleeping under the covers). The comfort temperature is assumed with 28° C. In principle, it would have not been a problem to replace that fix value by the floating T\(_{comf}\) of adaptive comfort models. Nevertheless, it was not done to make results and graphs easier to understand, as well as because adaptive comfort models are not adaptable for very high outdoor temperatures as the ones found in Cairo.

**Discussion of Results**

Two steps for optimising the constructions of a room have been explored. The first results of the simulations were gained by simulating the same room with different outer wall constructions. Twenty-three wall constructions were considered and a correlation between \(T_{opt}\) and U-value and TAD was observed (see Table 1). In the second step the thermal storage mass of the different room elements (internal and external walls, ceiling and floor) were put into question, and after simulating different constructions combinations with the respective storage capacities, a trend and a general rule have been found.

**Outer Wall Constructions**

By taking as a basis model a standard room with inner walls in aerated concrete (North and East walls), massive concrete ceiling and screed floor, the effects that twenty-three wall constructions have on the \(T_{opt}\) and \(T_{optw}\) indicators have been investigated and compared (see Table 1). The constructions simulated are partly found in hot and dry climates – be it traditional ones (adobe), or contemporary ones (concrete / insulation). It has been observed that there is a high correlation between \(T_{opt}\) and the U-Values of the constructions: the smaller the U-Value, the lower is \(T_{opt}\) (see Figure 3). Following this, it has been looked if a correlation between \(T_{opt}\) and TAD could be found; even if at a first sight the correlation is not strong (see Figure 4; left hand side), by focusing on the constructions with lower TAD, it is possible to observe that the ones with a lower TAD (<20 and specially <10) have a higher \(T_{opt}\) than the others (Figure 4; right hand side). By following these findings, it is possible to say that constructions with a low U-Value (<1.2 W/m\(^2\)K) and a TAD of above 20 are the ones that are to be recommended for this climate, especially if no cross ventilation is possible. Generally, constructions that have a low storage capacity, such as insulation (mineral wool), performed better than others. Therefore, all the constructions built with pure insulation or that have a massive inner layer with external insulation have a better \(T_{opt}\) as the others.
Table 1: List of constructions used for the simulations, quantities and results. All material exceeding the threshold of 1K (Toptw) or 6935 Kh (Topt) are marked in italic. (Class: T=Traditional; TC=Traditional and used in Cairo; C=Contemporary; CC=Contemporary and used in Cairo)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Insulation (mineral wool - 36cm)</td>
<td>C</td>
<td>0.10</td>
<td>85.7</td>
<td>2.2</td>
<td>3105</td>
<td>0.45</td>
</tr>
<tr>
<td>20 cm concrete + 36 cm insulation (mineral wool)</td>
<td>C</td>
<td>0.10</td>
<td>491.6</td>
<td>9.0</td>
<td>3267</td>
<td>0.47</td>
</tr>
<tr>
<td>Insulation (mineral wool - 24cm)</td>
<td>C</td>
<td>0.14</td>
<td>54.8</td>
<td>1.0</td>
<td>3306</td>
<td>0.48</td>
</tr>
<tr>
<td>Insulation (mineral wool - 12cm)</td>
<td>C</td>
<td>0.28</td>
<td>27.7</td>
<td>0.3</td>
<td>3714</td>
<td>0.54</td>
</tr>
<tr>
<td>aerated concrete (24cm) + insulation (min. wool - 4cm)</td>
<td>C</td>
<td>0.34</td>
<td>88.7</td>
<td>9.5</td>
<td>3934</td>
<td>0.57</td>
</tr>
<tr>
<td>aerated concrete (36cm)</td>
<td>C</td>
<td>0.39</td>
<td>96.9</td>
<td>12.2</td>
<td>4012</td>
<td>0.58</td>
</tr>
<tr>
<td>brick (24cm) + insulation (min. wool - 8cm)</td>
<td>CC</td>
<td>0.35</td>
<td>163.8</td>
<td>10.1</td>
<td>4194</td>
<td>0.60</td>
</tr>
<tr>
<td>light element (2xOSB 2 cm, 8 cm wood fiber)</td>
<td>C</td>
<td>0.46</td>
<td>19.3</td>
<td>4.4</td>
<td>4408</td>
<td>0.64</td>
</tr>
<tr>
<td>aerated concrete (24cm)</td>
<td>C</td>
<td>0.56</td>
<td>27.6</td>
<td>7.4</td>
<td>4454</td>
<td>0.64</td>
</tr>
<tr>
<td>adobe (36cm)</td>
<td>T</td>
<td>0.62</td>
<td>76.1</td>
<td>13.2</td>
<td>4693</td>
<td>0.68</td>
</tr>
<tr>
<td>hollow brick (36cm)</td>
<td>CC</td>
<td>0.67</td>
<td>38.0</td>
<td>10.0</td>
<td>4729</td>
<td>0.68</td>
</tr>
<tr>
<td>brick (24cm) + insulation (min. wool - 4cm)</td>
<td>C</td>
<td>0.58</td>
<td>86.4</td>
<td>9.9</td>
<td>4856</td>
<td>0.70</td>
</tr>
<tr>
<td>brick (60cm)</td>
<td>T</td>
<td>0.83</td>
<td>315.7</td>
<td>20.6</td>
<td>5383</td>
<td>0.78</td>
</tr>
<tr>
<td>brick (48cm)</td>
<td>T</td>
<td>1.00</td>
<td>102.6</td>
<td>16.4</td>
<td>5716</td>
<td>0.82</td>
</tr>
<tr>
<td>limestone (17.5 cm) + min. wool (1cm) + 2x Plaster (0.15cm)</td>
<td>C</td>
<td>1.39</td>
<td>17.6</td>
<td>7.5</td>
<td>5912</td>
<td>0.85</td>
</tr>
<tr>
<td>brick (36cm)</td>
<td>T</td>
<td>1.27</td>
<td>33.3</td>
<td>12.1</td>
<td>6100</td>
<td>0.88</td>
</tr>
<tr>
<td>adobe (40cm)</td>
<td>T</td>
<td>1.39</td>
<td>38.8</td>
<td>13.1</td>
<td>6368</td>
<td>0.92</td>
</tr>
<tr>
<td>limestone (36cm)</td>
<td>T</td>
<td>1.60</td>
<td>23.8</td>
<td>11.3</td>
<td>6633</td>
<td>0.96</td>
</tr>
<tr>
<td>brick (24cm)</td>
<td>T</td>
<td>1.71</td>
<td>10.8</td>
<td>7.8</td>
<td>6704</td>
<td>0.97</td>
</tr>
<tr>
<td>brick (21cm)</td>
<td>T</td>
<td>1.88</td>
<td>8.1</td>
<td>6.7</td>
<td>6984</td>
<td>1.01</td>
</tr>
<tr>
<td>brick (18cm)</td>
<td>TC</td>
<td>2.08</td>
<td>6.1</td>
<td>5.6</td>
<td>7357</td>
<td>1.06</td>
</tr>
<tr>
<td>brick (12cm)</td>
<td>TC</td>
<td>2.65</td>
<td>3.6</td>
<td>3.4</td>
<td>8541</td>
<td>1.23</td>
</tr>
<tr>
<td>concrete (20cm)</td>
<td>CC</td>
<td>4.00</td>
<td>3.5</td>
<td>5.1</td>
<td>9179</td>
<td>1.32</td>
</tr>
</tbody>
</table>

Figure 3. Correlation between Topt/Toptw and U-Value (all constructions). (Source: Authors)

Figure 4. Correlation between Topt and TAD (left hand side: all constructions; right hand side: zoom max TAD = 50). (Source: Authors)
As contemporary materials, mineral wool (36 cm; Topt: 3105 K) and aerated concrete (36 cm; Topt: 4012 K) obtained positive results. As traditional material adobe (36 cm; Topt: 4693 K) obtained good results as well. With a Topt of 4194 K another construction that performed well, is a combination between bricks (24 cm), and mineral wool (8 cm), whereas the authors could not proof the availability of this kind of insulation (while extruded polystyrene is widely used, especially for roofing).

**Storage Capacity of Different Room Elements**

After having discussed what are the physical characteristics that should be considered when choosing the construction materials for the outer walls in the context of Cairo (hot and dry climate), an insight is given into the thermal storage capacity of the optimised room. This is done with the aim to explore what kind of internal constructions make it possible to reach a low Topt.

The constructions that have been taken into consideration for the external constructions are adobe (45 cm), brick (36 cm), limestone (49 cm) and insulation (2.2 cm). The dimensioning was done to exclude the domination of U-Value on Topt, by keeping the U-Value constant (1.27 Wh/K m²). The internal constructions have been chosen as it follows: for internal wall, a massive light (aerated concrete plaster) and a light construction (gypsum board); for ceiling, massive concrete and suspended ceiling (with mineral wool); and for floor, screed and light construction (wood, gypsum, cement board).

The thermal storage mass of each construction has been calculated and different combinations were simulated. For external construction, consistency has been found by choosing materials with a high heat capacity (adobe, bricks, limestone). In the Table 2 it is possible to see the combinations explored, and the results gained both in terms of total storage capacity of the room, as well as well as on the potential for passive optimisation Topt. By looking at the correlation between Topt and the total heat storage capacity of the room (see Figure 5), there is hint that shows that storage capacity should not be too small, because for values below about 750 Wh/K Topt increase rapidly.

Thinking about the dimensions of the room taken as model (15 m²), it is possible to say that in this case it is recommended a minimal thermal storage capacity of 50 Wh/K m² area of usage. Both Table 2 and Figure 5 show that there are multiple possibilities to reach this value, nevertheless, there are also combinations of equipment that lie clearly below the threshold.

The meaning of that 50 Wh/K m² rule can be assessed also with another reflection: Generally, it should be avoided that the surface temperatures of the inner layers of the room surrounding construction elements reach remarkably higher values than the air temperature. As a rule of thumb, 1 degree difference should not be exceeded to keep comfort. With an average heat transfer coefficient of 0.13 m²K/W (value for walls and the mean between 0.1 for ceiling and 0.17 for floor lies in the same range) and 78 m² total inner surface of the room a heat transfer of 600 Wh/K would be possible per degree difference (78 m²/ 0.13 m²K/W = 600 W/K and thus during one hour 600 Wh/K). This result is quite near to the 750 Wh/K derived from the simulation. It allows to express the recommendation in another form: The minimum storage capacity of the room should be in the range of the possible heat transfer in Wh/K through all internal surfaces.

Further research done on the “Option 1” (see Table 2), and a deeper look at the daily results of the heat fluxes obtained by the room simulation, show that while Topt is 6206 [K] (and respectively Toptw 0.89 [K]), the strategy to have a higher thermal storage capacity is
Table 2: Room’s thermal storage capacity: list of constructions used for the simulations, quantities and results.

<table>
<thead>
<tr>
<th></th>
<th>External Constructions</th>
<th>Internal Constructions</th>
<th>Ceiling</th>
<th>Wall</th>
<th>Total Thermal Storage Capacity [Wh/K]</th>
<th>Topt [Kh]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adobe</td>
<td>Insulation</td>
<td>Screed</td>
<td>Light (wood / gypsum / cement board)</td>
<td>Massive concrete</td>
<td>Massive light (aerated concrete plaster)</td>
</tr>
<tr>
<td></td>
<td>45 cm</td>
<td>2.2 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2279</td>
</tr>
<tr>
<td>Option 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1704</td>
</tr>
<tr>
<td>Option 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1364</td>
</tr>
<tr>
<td>Option 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1042</td>
</tr>
<tr>
<td>Option 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>780</td>
</tr>
<tr>
<td>Option 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>467</td>
</tr>
<tr>
<td>Option 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>127</td>
</tr>
</tbody>
</table>

Figure 5. Correlation between Topt and total thermal storage capacity of the room. (Source: Authors)

in most part of the year positively affecting the end user’s comfort: during the day, allowing room temperatures lie below outdoor temperature, and during the night, while the heat gained during daytime is released, room temperature lies above outdoor temperature.

**Conclusion and Outlook**

The results obtained by this research have helped in understanding: 1) the priorities, the methodology and strategies that can be used for passive building optimisation in such climates; 2) the main characteristics of constructions that can help to achieve end user’s thermal comfort within the given context and conditions (e.g. no cross-ventilation); 3) the potential that simulation has as a decision-making tool.

Passive optimisation strategies used to improve the performance of a building in terms of thermal comfort and energy use are based on two basic points: 1) reduction of heat gains, and 2) removal of heat. Even though this paper’s focus has been given to the last point of the optimisation strategy, and that by choosing a model without cross ventilation it has not been possible what could be the “best case” in the context of Cairo (see Dietrich & Vignola, 2018), the strategy has proven to be logical, consistent as well as user-friendly.

By investigating into depth the physical characteristics of the building constructions, it has been possible to find out that the constructions that perform best for the external walls should have a U-Value below 1.2 [W/m²K] as well as a temperature amplitude damping (TAD) above 20. Furthermore, the thermal storage capacity of the room, which can be composed by different constructions, should be above the threshold of 50 Wh/K m² (area of usage) to absorb the hot air during daytime and release it when the external temperature drops.

International Conference for Sustainable Design of the Built Environment - SDBE London 2018
The optimisation strategy, the methodology used, and the use of the indicator $Topt$ and $Toptw$ to compare the models can be applied in different hot climatic contexts, and can be of help for practitioners that need a tool to simplify the decision-making process. That gives results at an early stage of a project, and a quite precise idea on the consequence that one specific decision taken during the process can have on end-user’s thermal comfort as well as on energy savings.

To be able to put into practice the lesson learned until now in a holistic way there are other steps that could be taken into consideration in future research: using this basis for studying traditional and contemporary buildings, and, through passive optimisation strategies, highlighting empirically the best ones for improving thermal comfort and decreasing energy consumption; researching and understanding local building customs (be it traditional or contemporary) and adapting the strategies in order to find solutions that are appealing and easy to be put into practice locally; proving the economic feasibility as well as the cultural acceptance of the optimised buildings.

References


THERMAL COMFORT, ENERGY AND ECONOMIC SAVINGS WITH THE USE OF SIRASOL IN HOUSES OF THE WEST CENTER OF THE ARGENTINE REPUBLIC.

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Abstract: The high costs that energy has reached entails the danger of not being able to maintain the houses at an adequate temperature in the cold months. An economic and thermally feasible response to these situations is the inclusion of natural air conditioning systems in the spaces of homes. Strategies and conventional passive heating systems, such as direct gain, Trombe walls or greenhouses among others, that take advantage of solar thermal energy can raise the interior temperature of the spaces to reach thermal comfort levels. However, there are spaces that do not allow the inclusion of these systems because they are without facades oriented towards Ecuador. In this context, a passive solar radiant heating system called SIRASOL has been developed. The objective of the work is to evaluate the comfort conditions and the potential for energy and economic savings with the use of SIRASOL in single-family homes in the provinces of the Argentine Republic: Mendoza, San Juan and La Rioja, through mathematical analysis and Energy Plus simulation software. Based on simulations with the Energy Plus software of a home with and without the use of SIRASOL, an increase of 5 ° C of the operating temperature was obtained, with an energy saving of 14.6% and 84% of comfort users. Extrapolating the energy savings of the homes of these provinces, it is noted that saving has two sides. a- INDIVIDUAL: the user will consume less energy, and b- SOCIAL: every 28 homes that the state builds, it will be possible to build another house considering the economic savings that implies.

Keywords: Energy and Economic Savings, Thermal Comfort, SIRASOL

INTRODUCCION

Global climate change and other threats to the energy and economic security of nations require the transformation of energy systems around the world that will end with dependence on the fuels that produce greenhouse gas emissions and that must be imported from far away places. (SWC, 2013).

The report of the Intergovernmental Panel for Climate Change mentions that the key sectorial mitigation measures, referring to buildings are: energy conservation, the use of renewable energies, passive solar heating, passive cooling, natural lighting and equipment energy efficient (IPCC, 2011). Other publications on the subject focus on this, noting that the development of renewable energy technologies together with progressive measures of energy efficiency reduce per-capita energy demand in the world (Renne and Lent, 2014 on SWC 2013). Improving the energy efficiency of existing buildings is essential, not only for the reduction of energy consumption but also to minimize carbon dioxide emissions and shovel climate change. (SARTORI AND HESTNES 2007, BONDÁN DE VASCONCELOS ET AL 2016, IRINA ET AL 2016).

Natural air conditioning systems are sets of building components whose main function is to improve their climate behavior without the use of any fossil-based energy source. They act on the radiant, thermal and air movement phenomena that occur naturally in architecture.
(Rafael Serra, 2006). The inclusion of these in the design of buildings gives a range of possibilities to reach thermal comfort levels and the environmental recovery of existing buildings.

In a context where the inclusion of natural air conditioning systems can reduce consumption and improve building energy efficiency, radiant heating systems have gained popularity due to advantages such as high thermal comfort, lower energy consumption and higher quality air in relation to conventional air conditioning systems (Rhee and Kim 2015, Babiak et al 2009).

In general, radiant systems for heating are formed by plates or radiant panels heated by hydraulic networks inside them or contiguously, which means the use of a source of electrical energy to reach the necessary temperature of the water. (Gingras and Gosselin, 2012). Under these considerations, the non-existence of radiant heating systems with direct / indirect use of renewable energy as a heat source for the radiant panel was observed. (Kyu et al, 2017).

In response to this failure, a radiant heating system was developed that uses solar radiation as an energy source. This system called SIRASOL (solar radiant heating system), is a passive radiant heating device located in the center of the ceiling of the space. This system allows the natural air conditioning of the space by means of a radiant panel, composed of a metal plate that captures the solar energy and delivers thermal radiant energy instantaneously to the space (Mercado et al 2013).

The present study analyzes the possibility of contributing to the energy and economic savings produced by passive solar radiant heating. The main objective is to evaluate comfort conditions and the potential for energy savings with the use of SIRASOL in single-family homes in the provinces of Mendoza, San Juan and La Rioja.

**Methodology**

The methodology of the work, was based on the analysis of the incorporation of SIRASOL in houses of the center-west of the Argentine Republic, this was executed by means of mathematical analysis and of the simulation program Energy-Plus (https://energyplus.net /), from the following points:

1. Using simulated models of a social housing and SIRASOL, calibrated and adjusted for previous studies (Mercado et al 2011, Mercado et al, 2011a respectively), the combination of both models is made to obtain a unique model of housing with the built-in syste.
2. The energetic behavior of the house is evaluated in two scenarios, WITHOUT the incorporation of the system with the housing model and WITH the incorporation of the SIRASOL from the joint simulation model. For this, two different thermostats are set in the Energy Plus program (Tai-1 = 20.5 ° C and Tai-2 = 17.5 ° C).
3. For the analysis of economic savings, the thermal-energy balance of the dwelling is carried out with the built-in system (Esteves and Gelardi, 2003). With the results of the energy demand of the house we proceed to calculate the economic cost that it takes.

**BACKGROUND. SIRASOL, Passive solar radiant heating system**
As mentioned above, the developed system responds to the use of solar energy as the energy source of a radiant heating system. In addition, we worked on the premise of increasing the solutions offered by the bibliography to the situation of spaces that can not be heated with conventional passive solar heating systems such as direct solar gain, Trombe wall, greenhouses among others. The main impediment to using this type of system is, in most cases, the lack of a facade facing Ecuador.

SIRASOL is a pyramidal elongated, skylight type, has four surfaces in contact with the outside and a surface that links it with the interior of the space to be heated, thus creating a cavity with little air movement. Three of the four surfaces of this enclosure have simple glass enclosures: the side facing the Ecuador that has an optimized slope, is the catchment element and the east and west sides act as auxiliary collectors, for the morning hours and late. The south side, opposite the larger catchment area, has a thermally isolated opaque roof that is inclined to minimize the loss surface. The surface that communicates with the space to be heated is a metal panel, called a radiant panel, the element that transfers solar energy as thermal energy to the interior environment (Figure 1). (MERCADO et al, 2005, 2007, 2009a, 2009b, 2010, 2013).

The radiant panel reaches temperatures close to 60 °C on a typical winter day. The solid elements of space raise their temperature thanks to the radiant exchange produced by SIRASOL. This generates that the average radiant temperature (TRM)\(^1\) of the room increases, causing an increase in the operating temperature (TO)\(^2\), being the temperature that the occupant will directly perceive. (MERCADO, 2011a).

The TO is considered as an evaluation parameter because it is defined from the physical parameters of comfort, (air temperature (TBS), average radiant temperature (TRM), humidity and air speed). It can be obtained according to the following expression (ISO 77300: 2005):

\[
TO = \gamma \cdot TBS + (1 - \gamma) \cdot TRM
\] (1)

Being \(\gamma\), the coefficient that depends on the air velocity (V):

<table>
<thead>
<tr>
<th>V[m/s]</th>
<th>&lt; 0.2</th>
<th>0.2 a 0.6</th>
<th>0.6 a 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\gamma)</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The air speed in the winter season in indoor environments and without the existence of centralized conditioning systems, can be considered practically nil. The international standard ISO 77300: 2005 establishes that for air speeds lower than 0.2m / s, it is possible to calculate the operating temperature (TO) as the average of the air temperature and the average radiant temperature.

\(^1\) TRM: Average Radiant Temperature is a weighted average of the surface temperatures of the walls and ceilings of a space, has a great impact on human comfort because, together with the air temperature, will determine the operating temperature.

\(^2\) TO: Operating Temperature, perceived or equivalent is the temperature that the occupant will directly perceive, is defined from the mean radiant temperature (TRM) and the air temperature (Gouldin et al, 1994).
Although the development of the system was carried out in the city of Mendoza, an area of arid climate and high potential of solar energy, these characteristics extend in the central-west zone of the Argentine Republic and particularly in the provinces of La Rioja and San Juan (Figure 2).

Note that the provinces share the same characterization of aridity regime and values in the same range of solar radiation. In relation to temperatures, Table 1 shows the average, minimum and maximum external temperature data. It is observed that the average and minimum temperatures do not exceed differences of 3°C between them, which is considered an incentive factor for the extension of the use of the system in the cities selected for the study. According to the above, it is considered viable to extrapolate the results of the city of Mendoza to the other cities.
Comfort and Radiant Exchange

International standards describe thermal comfort as a condition of the mind in which satisfaction is expressed with the thermal environment, the thermal sensation that is mainly related to the thermal balance of the human body as a whole (ISO 7730: 2005). This balance is influenced by physical activity, clothing, environmental parameters and forms of heat exchange. In this last aspect, it is found that the heat exchanged by the human body with its surrounding environment in thermal equilibrium conditions is in the following proportions: 26% by evaporation, by convection and conduction 32%, and by radiation 42% (where the variable intervenes: average radiant temperature).

According to Babiak et al (2009), thermal comfort is significantly affected by the average radiant temperature, especially in radiant spaces, such as a room with floor or ceiling radiant systems. A high radiant temperature can increase not only the temperature of the skin but also the operating temperature, resulting in an increase in PMV\(^3\) (ATMACA et al, 2007). In the case of an air-conditioned space with the system located in the center of the ceiling of the room, the

\(^3\) The Predicted Mean Vote (PMV) or Index of Average Valuation, defines its author as a measure of the thermal sensation of the average of a population in an environment.

### Table 1: Climate characterization of the cities of the Provinces of Mendoza, La Rioja and San Juan.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mendoza</th>
<th>La Rioja</th>
<th>San Juan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiación solar media sobre superficie horizontal [MJ/m² .día]</td>
<td>25.7</td>
<td>23</td>
<td>28.3</td>
</tr>
<tr>
<td>Temperatura media mínima [^{°C}]</td>
<td>22</td>
<td>20.75</td>
<td>19.2</td>
</tr>
<tr>
<td>Temperatura media [^{°C}]</td>
<td>23.6</td>
<td>27.3</td>
<td>26.7</td>
</tr>
<tr>
<td>Temperatura media máxima [^{°C}]</td>
<td>37.4</td>
<td>34.75</td>
<td>34.4</td>
</tr>
<tr>
<td>Humedad relativa [%]</td>
<td>51</td>
<td>62</td>
<td>44.6</td>
</tr>
</tbody>
</table>

Figure 2: Argentine maps, 1- zoning by regimes of aridity and June distribution solar radiation.
increase of the average radiant temperature increases between 2 to 5 ° C. (MERCADO et al, 2013).

The radiant exchange of the presented system is responsible for passively heating the space. Heating by means of radiant systems has advantages over heating given by convective systems such as: energy saving, the reduction of thermal stratification and the quality of indoor air. (MERCADO et al, 2009a, CARAZO ET AL, 2013, LIU et al, 2010, ISO 7730: 2005).

**Housing Situation**

The house has many definitions depending on the place from which it is observed. For society it is much more than a roof, it is the meeting place of the family. (ARGENTINE CHAMBER OF CONSTRUCTION, 2016). From the thermal aspect, concerning the present study, it is considered that it should be prioritized in housing projects of the State, due to two reasons: a- the habitability conditions provided by these dwellings affect a significant number of people and b- the expense of operation and maintenance that they generate are subsequently significant, considering the family budget available to most users. (Martinez, 2005).

In the social housing of the Argentine Republic, the building envelope is deficient in its thermal performance (CZAJKOWSKI et al 2012, COMPAGNONI 2008, D'AMICO et al 2012, BRAZZOLA 2006). Therefore there is a residential park built energy inefficient. In this context, the user is condemned to live in precarious thermal conditions, to sustain a high energy cost during the useful life of the home and is deprived of the possibility of making rational use of energy. The home does not provide the user with the minimum comfort conditions, even with a high energy consumption from conventional sources to thermally condition a home (MERCADO et al, 2010).

In relation to energy access and availability to thermally condition a home, around 40% of households in the country are disconnected from the natural gas network, using liquefied gas, firewood, electricity or other fuel. In addition, they pay a price 5 to 20 times higher per unit of energy than that corresponding to natural gas (ratio based on the cost of m3 of natural gas and its pair in liquefied gas of the social carafe).

<table>
<thead>
<tr>
<th>Provinces of arid zone of the center west of Argentina</th>
<th>Total housing</th>
<th>Total housing with availability of GN network</th>
<th>Total housing without availability of GN network</th>
<th>Percentage of homes with network availability GN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mendoza</td>
<td>539271</td>
<td>329565</td>
<td>165276</td>
<td>66.60%</td>
</tr>
<tr>
<td>San Juan</td>
<td>188946</td>
<td>89635</td>
<td>87522</td>
<td>50.60%</td>
</tr>
<tr>
<td>La Rioja</td>
<td>109182</td>
<td>12446</td>
<td>78651</td>
<td>13.70%</td>
</tr>
</tbody>
</table>

*Table. 2: Housing with availability of access to the natural gas network by province. INDEC. 2010*

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4 The social carafe is a plan of the Argentine National State with the purpose of subsidizing 79% of the cost of a commercial carafe destined to the population away from the natural gas network and providing greater equity in energy consumption.
Table 2 shows data on homes with access to the natural gas (NG) network for the provinces of La Rioja, San Juan and Mendoza. It can be seen that the percentage of homes with accessibility is low, given that in the provinces of interest for this work it reaches 51.5%.

Case studies and application
As a case of study and application, a social housing is taken with the incorporation of the radiant passive solar system (SIRASOL). The house has been previously studied through thermal monitoring, energy analysis of real consumption and thermal simulations in the Energy Plus program.


The study house was built in 2006, department of Las Heras, province of Mendoza. It is located on the outskirts of the city, at the foot of the mountain range of the Andes (Figure 3). The house has a functional scheme and a constructive system that is repetitive in most of the country.

Figure 3: Plant and photographs of a house.

The constructive system is the traditional one for the region, solid common bricks (7 x 16 x 28 cm) revoked on both sides, leaving a wall thickness of 0.2m and inclined light cover, composed of pine masonry of the inner side, glass wool as an inch thick insulation and sheet metal as outer protection. It has a covered area of 63 m2 where a unique day space (kitchen-dining room), a bathroom and two bedrooms are solved. The form is resolved in two prismatic bodies
juxtaposed. The envelope is 146.46m², 70.3m² corresponds to exposed walls, 13.5m² corresponds to boundary walls and 62.7m² corresponds to ceilings.

RESULTS
The adjustment of the model of the house in the spring season is presented because the house does not use mechanical conditioning systems that alter the thermal behavior of the house, the adjustment of the model of the system and the conjunction of both models. The Energy Plus program was developed by the US Department of Energy based on BLAST and DOE2 codes. This program was used because it independently contemplates the exchange of heat by radiation, which allows the incorporation of SIRASOL in the home and the obtaining of data of average radiant temperature and operating temperature.

Housing model
The housing data were entered into the program according to how they are presented in Table 3. The simulation was run using the climate file *.epw format requested by the Energy Plus program as a climatic basis. This file was made with data from the Argentine National Meteorological Service and measured data (outside temperature and radiation) of the monitored period.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Living room</th>
<th>Bath room</th>
<th>Hall</th>
<th>Bedroom1</th>
<th>Bedroom2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls without mass</td>
<td>Description</td>
<td>Internal and external wall: brick whit plaster</td>
<td>Floor: concrete subfloor</td>
<td>brick= 0.73; plaster=0.93; concrete= 1.63; earth=0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R [m²°C/W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Convective coefficients [W/m°C]</td>
<td>mathematical algorithm calculated by the program</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n° air renovations/hour</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table1: Data considered of the FONAVI housing as inputs to the EnergyPlus.

The simulation covered the whole house, however the adjustment obtained in the being for being the space where the system will be included for the days between September 21 and 24 is presented. From the simulation it turned out that the biggest difference between measured data and simulated data occurs at noon, during which time the household has an increase in internal profits as a result of cooking food. For the rest of the day, the error between measured and simulated data does not exceed 1°C. Figure 4.
SIRASOL model

The data of the system model were entered into the program as presented in Table 4. Like the housing, the temperature and radiation data of the adjustment period were replaced by monitored data (July 1 to 12).

The prototype model data was entered into the program as follows: the system and the receiving site as two different thermal zones, called SIRASOL and space respectively. The enclosures were considered in relation to their actual materiality, corresponding to mass walls and light walls belonging to the space zone. For the system, lightweight enclosures were considered: radiant panel (only connection between the Space area and the SIRASOL zone), north, east, west and south cover walls; connected to the outside. For the walls, the following values were used: brick $\lambda=0.73\text{W/m}^2\text{°C}$ and for floor: concrete $\lambda=1.63\text{W/m}^2\text{°C}$. For the light partitions the program requests the resistances of the materials, for vertical partitions (space) $R=0.31\text{m}^2\text{°C/W}$ and for the partitions of the system $R=0.00019\text{m}^2\text{°C/W}$. The convective coefficients used were for the external elements $10.38\text{W/m}^2\text{°C}$ and for the internal walls $1\text{W/m}^2\text{°C}$. The number of air renewals per hour was set at 1 for the premises and 0.1 for the system, due to its watertight condition. The simulation of the model was satisfactory, in Figure 3 the simulated measured radiant panel temperature is presented (Mercado et al, 2011a).

![Figure 4: Measured and simulated indoor air temperature (Tai).](image)
Unification of simulation models: Housing + SIRASOL

The previous models (housing and system), were combined obtaining a unique simulation model of the house with SIRASOL incorporated into the living space. The simulation period was comprised between June 1 and August 31, with the purpose of evaluating the entire winter period. The climatic file was used with statistical data of the city of Mendoza, armed according to the format established by the software.

The Energy-Plus program allows you to set thermostat-type air temperatures for energy analysis. In the first instance it was set at 20.5 °C, since it is considered a temperature within the thermal comfort range. However, considering the impact of the system on the radiant exchange and its influence on the operating temperature, the air temperature can be lower - up to 3 °C according to what is established by ASHRAE 55 -, minimizing the sensation of comfort of the person. Following the energy saving study line, a thermostat is set where \( T_{ai} = 17.5 \) °C reaching a \( T_{o} = 20.5 \) °C; the user will feel thermal comfort because the temperature that will be perceived will be the operating temperature. (Market, 2011)

Energy Saving and Thermal Comfort

The simulation showed as a result that the use and operation of the system makes it possible to reduce 8.8% of fossil-based energy consumption in the space heated by the system. (Table 5).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Energy needed to maintain an air temperature= 20.5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing without SIRASOL in Living room</td>
<td>784.4</td>
</tr>
<tr>
<td>Housing with SIRASOL in Living room</td>
<td>715.3</td>
</tr>
<tr>
<td>Saving percentage</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Table 5. Required time energy of the day space to maintain an air temperature of 20.5 °C WITHOUT and WITH the system in operation and, percentage of savings achieved.
As mentioned above, the same previous analysis is carried out by changing the air
temperature Tai2 = 17.5 °C. In this case, the results show a higher energy saving of the order
of 14.6 (Table 6).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Energy needed to maintain an air temperature= 17.5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing without SIRASOL in Living room</td>
<td>438</td>
</tr>
<tr>
<td>Housing with SIRASOL in Living room</td>
<td>373.8</td>
</tr>
<tr>
<td>Saving percentage</td>
<td>14.6</td>
</tr>
</tbody>
</table>

Table 6: Hourly energy required of the day space to maintain an air temperature of 17.5 °C and an operating temperature of 20.5 °C, SIN and WITH the system in operation and, percentage of savings achieved.

The savings achieved falls directly on the consumption of energy used for heating, being
the destination of greatest incidence within the annual energy consumption of a house.

**Economic savings**
The use of the solar resource through the system would imply that more people would feel
comfort in their homes, decreasing the regional consumption of fossil energy and the debts
contracted by users who use the resource. According to the elimination of subsidies that are
taking place in the country (BIDEGARAY, 2015, 2016 and LA TECLA.INFO 2016), it is possible to
affirm that the era of cheap energy is over and that, therefore, we are faced with a moment of
conservation and care of energy.

According to the thermal balance made for the house, 1395.7m3 of natural gas is needed
to heat it. With the system it is possible to reduce this consumption to 1192 m3, thus reducing
the consumption of fossil energy. (Table 7).

<table>
<thead>
<tr>
<th></th>
<th>house WITHOUT SIRASOL</th>
<th>house WITH SIRASOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary energy needed [KWh/año]</td>
<td>15102</td>
<td>12897</td>
</tr>
<tr>
<td>Energy to heat natural gas (GN) [m³]</td>
<td>1395</td>
<td>1192</td>
</tr>
<tr>
<td>cost to May 2018 GN [USD]</td>
<td>275.3</td>
<td>235.3</td>
</tr>
<tr>
<td>Energy to heat compressed liquefied gas (GLP) [Kg]</td>
<td>1159</td>
<td>990.3</td>
</tr>
<tr>
<td>cost to May 2018 GLP [USD]</td>
<td>1093.4</td>
<td>934.2</td>
</tr>
</tbody>
</table>

Table 7: 
Need of energy for heating KWh/ year y m³

The annual energy cost differs substantially between natural gas and liquefied gas,
reaching a difference of up to 10 times. Considering the economic savings of the inclusion of
the system in the housing and the amortization of the initial investment to build the system, it
differs in a house with access to the natural gas network and the one that does not have it. For
housing with access to the network, this will be 4 years, while for housing without access it will
be 6 months. This situation is not minor because, as presented in table 1, the availability of
natural gas (NG) is low. The province of La Rioja presents the highest percentage of households
disconnected from the GN network. However, in the provinces of San Juan and Mendoza,
where these values are lower, the number of buildings is higher. Therefore, the inclusion of the
system would positively affect 331,449 households in the region.
Another aspect of economic savings is based on the fact that social housing is financed mostly by the state in 20 years. At the rate of supply of GN in the country, it is feasible to warn that they will be homes built outside the reach of the distribution network.

In relation to the economic cost of construction of the system is $ 4090 (1US $ = $ 26.5)^5, involving 0.68% of the investment of a social housing type. This value can be reduced if carried out by self-construction.

CONCLUSION

The savings achieved falls directly on the energy consumption Used for heating, being the destination of greatest incidence within the annual consumption of a house.

The environmental and energy revaluation of homes without energy efficiency considerations in their original designs is possible through the use of SIRASOL, which gives the space heat in radiant form, increasing the reach of thermal comfort. With the use of the system in the poor family homes can be a factor that improves the internal thermal situation, freeing them from economic costs for energy, which in many cases, can not be addressed.

The result obtained indicates the possibility of achieving an energy saving for heating in homes of 14.6%. This is very important because it concerns social housing. As could be seen in the analysis of the region, the number of households without access to the natural gas network reaches 60.42%. The incorporation of passive solar heating systems in these dwellings would improve the quality of life within the interiors of these spaces, the SIRASOL as such, the incorporation of the façade facing Ecuador into the independence, which enhances its use in these buildings.

It is possible to improve the thermal situation of the house with other interventions such as energy conservation. However, this requires a greater investment than what is needed for the placement of SIRASOL (12 times more^6). Given that they are homes that have characteristics of lower middle class economic, the actions of improvement must be met with economic requirements, easy and fast execution, advantages that present the system in question.

Concluding finally, the importance of SIRASOL is emphasized because it allows the use of a passive heating solar system without a north facade. It is a system sensitive to the incidence of solar radiation. This supplier of heat in interior spaces instantaneously in locations where there are diaphanous skies with a solar incident radiation greater than 450 W / m2. These conditions are present in many cities in Spain, Italy, Greece and Portugal, to name a few in the Northern Hemisphere, where the replicability of SIRASOL is feasible.

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6 Ratio calculated from the total cost of one meter of thermal insulation (expanded polystyrene 5 mm thick) by the vertical envelope of the house. Total surface area = 84.96m2, cost of insulation + support structure + completion reboke = $ 1050 (US $ 39).
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Typological Analysis of Residence’s Implantations at Siqueira Campos Neighbourhood

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Abstract: The practice of self-construction is commonly accomplished without professional orientation in the Brazilian cities. In Aracaju, Brazil, it is not different and countless units are observed under this status that damages thermal comfort conditions, consequently to salubrity and energy efficiency. The objective is to analyse typology of residences’ implantations through studying their auto-interventions, as reforms and constructions. For this purpose, it was required to collect constructive characteristics of houses to identify applied techniques for improvement of thermal comfort and to monitor indoor air temperatures and air speed. It was identified one typical block at a consolidated central district and it was selected houses for data collecting of architectural design, indoor air temperature, and air speed. In addition, it was applied interviews to check thermal comfort residence perceptions. It was verified some dwellings have irregularities in openings for air inlet; considering Aracaju has a warm and humid climate. The solution more applied to gain some natural ventilation was a type of light well in roofing through some air can entry and promote cooling into dwellings, air renovation and satisfy thermal comfort perceptions of residents. However, that solution has improved thermal comfort in houses according to interviewees; despite not always residential openings have appropriate dimensions and air directors. It was observed some improvement in indoor air speed when the light well was associated with other openings due to air canalization. It is common some rooms have no windows to the outdoors in most of the dwellings in the neighbourhood and in the city because it is a social aspect of that low-income population. The contribution of this study is to document possible technical solutions, serving as a reference for futures neighbourhoods and for edition and supervision of current legislation.

Keywords: Thermal comfort, Health, Well-being, Residences, Light well

Introduction

The indoor air quality has been the focus of plenty of research for all over the world due to damages caused to humanity since Industrial Revolution age. Studies began in industrial spaces because of requirements of environmental and labour regulations. However, According to Gioda and Aquino Neto (2003) about indoor air quality in no-industrial spaces, studies just began in the 70s when there was the development of energy consumption control in buildings. More recently, that concern extended to residential spaces, related some disease appear in more than one individual of the same family due to lack of salubrity in that space. The thermal indoor environment in the building is very significant because most people spend around 90% of their time in building mainly in the mild climate location. Therefore, the optimal thermal indoor environment is necessary for the whole populace, according to many authors (Skoog et al., 2005; Zhang and Niu, 2003; Sookchaiya et al., 2010). Major physical factors which affect the thermal indoor environment are air
temperature, relative humidity, air movements and radian temperature (Skoog et al., 2005; Holm and Engelbrecht, 2005; Pfafferott et al., 2005; Sookchaiya et al., 2010).

The ventilation effects on indoor air quality and health are a complex issue. It is known that ventilation is necessary to remove indoor-generated pollutants from indoor air or dilute their concentration to acceptable levels. Ventilation, among other functions, may be used to control the thermal environment or humidity in buildings in many cases. The existing literature indicates that ventilation has a significant impact on several important human outcomes, including communicable respiratory illnesses; sick building syndrome symptoms (in case of mechanical ventilation); task performance and productivity; perceived air quality among occupants or sensor panels respiratory allergies and asthma (Seppänen and Fisk, 2004). However, Wolkoff (2018) concludes in his studies that elevated relative humidity may reduce complaint rates and favour work performance in offices in comparison with very dry conditions, but more information is needed to understand how humidity influences symptom reporting and the performance.

Natural ventilation related health in residences, and consequently human well-being and thermal comfort, is an unusual research subject. Sundell et al. (2011) have found 12 relevant papers focused on office subject while have found only 4 to residences, 4 to schools, 2 to hospitals and 1 to jail of 74 papers chosen for that review. It is may be explained due to the need of research data for consolidation and enhancement of labour laws in most countries. In addition, they affirm of total papers judged as conclusive or suggestive cumulatively described 8 carried out in Sweden, 7 in the USA, 3 in Finland, 2 each in Denmark and Canada and 1 in Norway. Incidentally, none of the papers reported on their studies carried out in Asia, South America or Africa. Most researchers have done studies in mild or cold countries, which have different implications in tropical areas. A pollutant may be emitted by the fabric of buildings and may be a by-product of the activities that are undertaken within them. Whether pollutant occurrences depend on them coming from biological or non-biological sources (Jones, 1994), warm and high relative humidity may contribute to biological pollutant growth. On the other hand, ventilation, among other functions, may be used to control the proliferation of biological pollutant on the indoor thermal environment in many warm locations. Tropical areas have excellent conditions for fungi and bacteria growth that may result in some human health disorder as allergies, sinuses among others. Houses under that climate conditions should permit exposure to solar radiation in early daylight for attenuation of pollutants from biological sources and no permit excess heat transfer to indoor environments.

As stated in Sundell (2004), in many studies (including more than 100,000 people) an association have been found between living or working in a “damp” building and health effects, such as a cough, wheeze, allergies and asthma (Sundell, 1999; Bornehag et al., 2001). However, there are also indications that other health effects such as general symptoms (e.g., tiredness, headache, etc.), irritation and airway infections are associated with dampness. Relative risks, commonly indicated by odds ratios, are similar for infants, children and adults, in homes and at workplaces, in the range from 1.4 to 2.2. Accordingly, in houses located in tropical areas as the most of coastal lands in Brazil, it has high temperatures to be added to indoor environment becoming excellent to the proliferation of fungi and bacteria. They may involve some health disorder. Ineffective ventilation and lack of sunlight contribute to reducing acceptable levels of germs by the human immune system. The lower quality of houses added precarious access to basic sanitation; potable water and envelope to block vector entry that carries a most of diseases contribute to losing health
quality and human well-being. In addition, the occupants make use of mechanical equipment as fans to improve the indoor thermal comfort. In this regard, this paper aims to study found solutions in implantation typologies of houses located in a typical block at neighbourhood Siqueira Campos, in Aracaju, Brazil, to improve thermal comfort perceptions of residents.

Characterization of study object and methods of data acquisition

Aracaju, the smallest state’s - Sergipe - capital is one of the youngest Brazilian major cities. In accordance with Köppen-Geiger, it has a climate As, i.e., tropical climate with high temperatures during the dry summer season, the maximum annual average temperature of 29.30°C, mild temperatures in rainy winter, the minimum annual average temperature of 23°C. The annual average temperature is 26.3°C. The annual average precipitation is 1300.2 mm, however, in some dry months, it does not reach 60mm (INMET, 2018). As claimed by Bioclimatic Zoning Standard (ABNT, 2005), it is contained in bioclimatic zone 8 which includes some recommendations, e.g., solar protection of openings that should be large (≥ 40% to room’s floor area), to allow ventilation to remove heat and dampness.

The Siqueira Campos neighbourhood is located in West Zone in Aracaju (Figure 1), that is one of the most consolidated regions of the city. The neighbourhood developed from railroad’s implantation in 1915 and has commercial and residential uses, predominantly row houses that have Portuguese architectural heritage. According to Reis Filho (1977), this type of construction was diffused widely among the low-income population, especially in the Northeast of the country. Many usually are narrow and long in that area, as well as, houses are a type of “door and window” construction. That term invokes few existing openings, which characterize houses by a deficiency in lighting and ventilation. Usually, dwellings are constructed or reformed by their residents without professional assistance as architects and engineers and, because of this; they present peculiar aspects.

Figure 1. Siqueira Campos’ localization in the city of Aracaju. Source: Adapted from Google Earth, 2018.
Thus, it was noticed the use of a tool to improve the lighting and ventilation in medium region of residences, quite common in the neighbourhood, the light well which application was observed also to ventilation, not project roofing (Figure 2). In ABNT (1999), the light well is an internal vertical space in the house to capture daylight and natural ventilation for internal rooms in buildings. There is some wall to direct the air entrance on the top and there are windows or doors in the bottom through rooms can be cool in most cases. Usually, its surfaces are recovered with high reflectance materials for lighting use (Martins, 2011) and according to the same author; it is common in row houses because it uses to save energy for artificial lighting and mechanical ventilation. That tool when correctly applied may provide effective strategies for air renovation and thermal comfort to residents (Martins et al., 2010). One of its advantages is to provide light distribution without receiving direct solar radiation (Martins, 2011).

For research delineation and due to the large extent of the area was necessary to carry out neighbourhood’s analysis to find a block that represents typical constructions. Thus, to characterize the study object, it was applied, through analysis of the dimension of the lots on-site visits and aerial images (Google Earth) for applicability to the criterion of the block that has most half-houses, row houses and the predominance of single-family residential lots, in which they were located in narrow and long lots. Therefore, the typical block is located between Bahia, Porto Alegre and Sergipe Streets and Bahia Lane. The block has 32 lots, and 27 of them are residential use. In that, it synthesizes the presence of the typological characteristics of implantation identified and the presence of the strategy of environmental comfort characteristic of the neighbourhood (Figure 2), the light well.

Subsequently, it was realized a typology residence survey in relation to its implantation at lot through on-site visits and aerial images (Google Earth). The houses were classified according to following classifications: typology 1 to semi-detached house, in other words, a construction with only one of the sideline with setbacks; typology 2 to row houses, such as no setback in both sidelines; and typology 3 to isolated residence that has setback in both sidelines. By criterion dweller permission, it was identified five dwelling units (I, II and III to North orientation; IV and V to South orientation) in both orientations of the block, and it was realized cadastral survey of them with the identification of applied strategies to improve natural ventilation. It was used a portable hot-wire anemometer (Figure 2) for collecting data of air temperature (C⁰) and air velocity (m/s) in some points of dwellings, as well as photographic register, from March to July 2017.

![Figure 2. The light well in 2 examples and portable hot-wire anemometer](image)

It was realized current legislation query in order to choose criteria to study five homes. According to City’s Master Plan for Urban Development (Plano Diretor de Desenvolvimento Urbano - PDDU) the district is located in Preferential Area of Densification.
2 (Zona de Adensamento Preferencial 2 - ZAP 2) (PMA, 2000) that has municipal requirements about setbacks and occupancy rate in the lot. The minimum front setback is 3 meters to North and West orientation and South and East orientation is not a mandatory setback. Rear and side setbacks are not mandatory and occupation rate is 90% in reference to the total area of the lot. The guidelines in the Construction and Buildings Code (PMA, 2010) guide to the light well, to lighting and ventilation, must attend the following requirements:

- Access for inspection;
- A minimum area of 1.60m² and a minimum width of 0.80m;
- The light well has an area with a circle of 1.50m diameter, and it is sealed by walls in its perimeter.

Residents of five dwellings were interviewed to obtain data of thermal comfort perception. According to Pinheiro & Günther (2008), the applied method is reactive (invasive way) where direct interactions are installed with residents through interviews. Structured interviews were composed in the first part by questions about the location and characteristic residences such as room and window numbers. In the second part, there were dichotomous questions about thermal comfort perceptions of residents:

- Q: Do you think your home is well ventilated? A: (Yes) (No)
- Q: Do you think your home is damp? A: (Yes) (No)
- Q: Is there any wall with infiltration or peeling? A: (Yes) (No)

Results

In the initial survey of 27 residential lots, only 24 of them were possible to identify implantation typology (Figure 3). It was observed 38% of those 24 identified lots have typology 2, in the other words; they compose a row home that is only possible to capture natural ventilation by windows through the rear and front setbacks. It was 62% with typology 1 that there was one setback in one of the sides and in those cases, it was possible to expand windows to natural ventilation capture in the side setback. The light well use is notably necessary for typology 2 because founded constructive characteristics.

Access permits were granted in only five residences that were identified by I, II, III, IV and V in Figure 3. Their façades were presented in Figure 4 as well as their architectural design were shown in Figure 5 for a better understanding of internal rooms and their openings. It was observed most of the residences have six rooms (30%), seven rooms (20%), and eight rooms (30%) in the realized survey. 40% of them have four windows in the home and 20% have three windows. In 60% of dwellings, there are light wells as a strategy to achieve natural ventilation. Residences I and IV have an architectural design more potentially damaging to human health, not complying with current legislation. There are two rooms for long permanence (sleeping room) with no openings to outdoor for accomplishing air changes to keep a minimum of oxygen needs to human beings in the residence I.
Furthermore, natural ventilation to remove heat and moisture in the tropical climate is necessary to improve thermal comfort perception and health, avoiding becoming sick due to fungi proliferation. The solar radiation is positive to health due to the ultraviolet spectral range helps to exterminate germs and fungi, which usually cause allergies and respiratory diseases. There is the same condition in the residence IV and there is no window in the bathroom, which is a place naturally humid and easy to generate moulds, slime and fungi. However, in this case, it is possible to construct a window in one of the rooms.
The strategic use of light well to natural ventilation is found in residences II, III and V (Figure 6). It was observed they are applied to thermal comfort in different dimensions and localizations in residences (mainly in the middle). Usually, winds and the sun come into dwellings through windows arranged in the light well. In some of the light wells, there is concrete beams are used to prevent superior access by intruders. Besides their uses, it was observed others tools, as side aisle and backyard that are very important to air inlet in houses despite they are mandatory by legislation (Table 1). Because climate conditions and reduced constructive dimensions of light well one predominant characteristic is mould proliferation (Figure 6) which could provoke air contamination into houses.

One of the main objectives of urban legislation is to ensure quality in the building environment, form acceptable minimum parameters that guarantee hygiene, health and comfort conditions (Fernandes, 2011). Data from the constructive survey (Figure 5) were
evaluated according to parameters of current legislation: Master Plan of Urban Development (PMA, 2000) and guidelines in Construction and Buildings Code (PMA, 2010) in the Table 1 that relate occupation rate, setbacks of buildings, and minimum values of width to light well for example.

![Figure 6. Images of light well to natural ventilation in dwellings II, III e V](image)

<table>
<thead>
<tr>
<th>Constructive requirements</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>Regulatory parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum front setback</td>
<td>0m</td>
<td>0m</td>
<td>0m</td>
<td>0m</td>
<td>0m</td>
<td>I, II, III – 3m</td>
</tr>
<tr>
<td>Rear setback</td>
<td>5.0m</td>
<td>3.65m</td>
<td>4.0m</td>
<td>4.8m</td>
<td>7.2m</td>
<td>Not mandatory</td>
</tr>
<tr>
<td>Side setback</td>
<td>0m</td>
<td>0m</td>
<td>1.65m</td>
<td>0m</td>
<td>0m</td>
<td>Not mandatory</td>
</tr>
<tr>
<td>Occupation rate</td>
<td>79.4%</td>
<td>84.2%</td>
<td>65.7%</td>
<td>80%</td>
<td>67%</td>
<td>Maximum 90%</td>
</tr>
<tr>
<td>Light well access</td>
<td>-</td>
<td>No</td>
<td>Yes</td>
<td>-</td>
<td>No</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Light well minimum area</td>
<td>-</td>
<td>1.44m²</td>
<td>1.13m²</td>
<td>-</td>
<td>0.92m²</td>
<td>Minimum 1.6m²</td>
</tr>
<tr>
<td>Light well minimum width</td>
<td>-</td>
<td>0.70m</td>
<td>0.83m</td>
<td>-</td>
<td>0.92m</td>
<td>0.80m</td>
</tr>
</tbody>
</table>

In three of five dwellings, there was a light well to natural ventilation. No one of them complies with all requirements present in the legislation. When it referred to light well access for space maintenance, only one has accomplished to the guideline. In relation to the minimum area of 1.60m² to capture natural ventilation, no light well has accomplished that item. Moreover, about minimum width, only one light well in the dwelling II has not achieved that aspect despite the larger area.

In the rear setback concern, all dwellings have enough measurements, values among 3.65m e 7.2m. The dwellings have a few openings (windows) due non-attendance of the side setback (Figure 5), the rear and front area importance is becoming main spaces for natural ventilation. Not one residence has a front setback, however, it is mandatory to have 3m for the residences I, II and III. It is non-mandatory regarding the residences IV and V. About the side setback, only one of them has it because its lot is wider (8.3m) than others (7m), which permits air circulation.
Occupant perceptions of thermal comfort and monitored data

The interviews were applied in five houses in March 2017 because in only these residents permitted it. According to the data (Table 1), it was observed most of the residents consider their houses have not excessive humidity, infiltrations and damages to walls. In relation to the residences to be damp, the answers were 10% have moist while 90% did not be considered humid. Concerning the thermal perception of residents, 60% considered their dwellings poorly ventilated. Considering natural ventilation in the rooms is realized by one of constructive strategy as windows or light wells, the data become residences’ perception about temperature and air stagnant were accurate. 60% of dwellings have a side setback or light well while 40% of them have none of those characteristics. Two residences of all were considered ventilated by their residents while others were not considered ventilated.

All residences have an external area in the backyard and the door usually accesses that area is in the same direction as the entrance door, which makes a type of winding path. That fact assists to refresh the house’s rooms. Thus, the outdoor area (at the rear setback) is an important space for ventilation in the residences.

At the same time, interviews were made; it was collected data about air temperature and air speed in each home (Table 2). The measurement locations were identified in each residence as A (external), B (internal) and C (light well) in Figure 4. The outdoor average air temperature was 32ºC and the outdoor average air speed was 1.0m/s.

Residences I and IV, which do not have the light wells, there is no great air temperature variation from outdoor (location A) to indoor (location B), around 0ºC and 0.1ºC respectively. Especially in the dwellings II, III and V (having the light well), the air temperature variation was around 1.9ºC, 0.7ºC and 1.0ºC respectively. Therefore, the residences which have the light well, there is a thermal variation compared to residences that have no one.

Due tropical climate (warm and humid), there are some constructive strategies that can be adopted to improve thermal quality in houses. Those techniques are proposed to take advantage of natural ventilation and to prevent dampness in buildings from excessive rainfalls. In relation to ventilation, there are higher ceilings that may be used to facilitate ventilation; openings in roofing that may improve air circulation; large windows and wind towers. In terms of preventing humidity from the rain, it is recommended waterproof roofing plus a great border to protect openings and to maintain ventilation even in the rainy season, waterproofing walls and floors to repel moisture on them.

It was also found that legislation is precarious and mandatory values need to be revised because they do not guarantee a minimum of life quality in those residences. The need and importance of more studies on this subject are to provide subsidies for improvement of those regulatory parameters. The inspection of legislation compliance and the social function of architects are important for cooperation in technical assistance in those residences of that neighbourhood and to other areas in the city.

As well the study of light well in row houses, this strategy of thermal comfort is present in different types of buildings, as Kotani et al. (2003) analyses the use of light well in high-rise with acquisition of data on the rate of wind-induced ventilation and thermal balance in light well. Then, developing a simple calculation method, which is not the purpose of this study, but will serve as a reference for later stages.
Table 2. Air temperature (T) and air speed (s) monitored into dwellings

<table>
<thead>
<tr>
<th>IDENTIFICATION</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION A</td>
<td>T=27.2ºC</td>
<td>T=30ºC</td>
<td>T=29.3ºC</td>
<td>T=28ºC</td>
<td>T=28.9ºC</td>
</tr>
<tr>
<td></td>
<td>s=0.5m/s</td>
<td>s=6.1m/s</td>
<td>s=0.6m/s</td>
<td>s=6.1m/s</td>
<td>s=0.8m/s</td>
</tr>
<tr>
<td>LOCATION B</td>
<td>T=27.2ºC</td>
<td>T=28.1ºC</td>
<td>T=28.6ºC</td>
<td>T=27.9ºC</td>
<td>T=27.9ºC</td>
</tr>
<tr>
<td></td>
<td>s=0.7m/s</td>
<td>s=0.4m/s</td>
<td>s=0.2m/s</td>
<td>s=3.2m/s</td>
<td>s=0.7m/s</td>
</tr>
<tr>
<td>LOCATION C</td>
<td>INEXISTENT</td>
<td>T=27.6ºC</td>
<td>T=28.2ºC</td>
<td>INEXISTENT</td>
<td>T=28.1ºC</td>
</tr>
<tr>
<td></td>
<td>s=1.1m/s</td>
<td>s=0.5m/s</td>
<td>INEXISTENT</td>
<td>s=0.6m/s</td>
<td></td>
</tr>
</tbody>
</table>

**Final Considerations**

The quality of residences’ design may assist to improve thermal comfort indoor conditions, in terms of indoor air quality, contributing to the health and well-being of residents. It was verified two predominant typologies through the carried out surveys in one of the oldest city districts, which do not favour those conditions nor does the legislation ensure them.

It was determined the light well has beneficial effects for improving thermal comfort at dwellings of the Siqueira Campos neighbourhood from obtained results. However, that strategy for cooling depends on many factors as its location in architectural design, which interferes in the quality of residence’s ventilation. In addition, the light well’s dimensions are another determining factor for its effectiveness, mainly in typology 2 that there are no setbacks on both sides. In typology 1, residences have air renovation through openings in the backyard and side corridor, but if not positioned correctly from basic information such as the direction of the prevailing winds, these strategies will not reach the maximum potential. The residence III in which it is of type 1 has light well and side corridor, but obtained the slowest air speed.

The light well shows a design solution to improve more natural lighting and ventilation, essentials elements to human health, to semi-detached houses or in a row due absence of setbacks. The light well benefits depend on dimensions, location in dwelling and wind catchers. Despite application possibility of light well in others warm and humid regions with row houses, it is important to evaluate local microclimate to ensure its efficiency.

Despite the light well being a strategy that assists to improve thermal comfort, it works as response to the window’s lack due to constructive reality of the neighbourhood (row houses, narrow and long terrain) and self-constructive have culminated in a solution without optimization its potential (minimum dimensions, minimum area, materials, location at architectural design). Therefore, residents consider their houses warm and poorly ventilated although the light well use. It is important the technical assistance from qualified professionals, as architects and civil engineers for the situation improvement in the community and city.

Poor indoor air quality may carry implications on the quality of people’s health, which would result in a negative influence in the Brazilian public health system due non-compliance with legislation, without guidelines more appropriate to solve the conflict.
between architectural design and climatic conditions. It is hoped that more discussions about that theme may guide new searches and data.

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