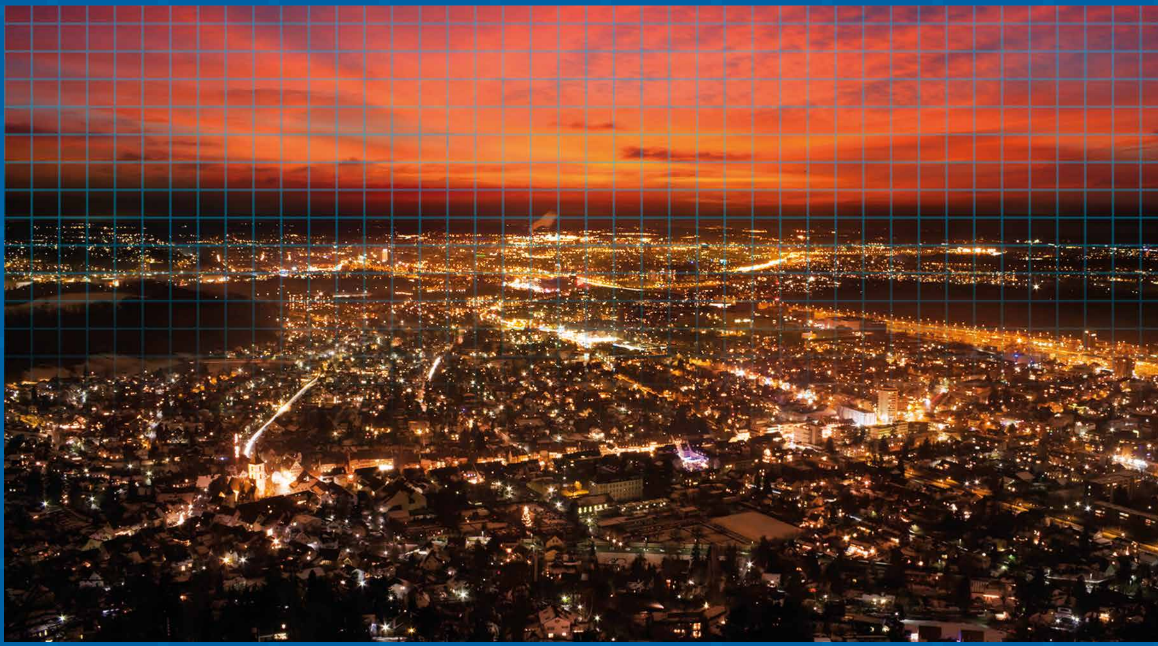
WIT Transactions on

The Built Environment

VOLUME 183, 2018

WIT PRESS



Eco-Architecture 2018

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EBSCO Publishing : eBook Collection (EBSCOhost) - printed on 2/8/2023 10:22 AM via
AN: 2014921 ; Syngellakis, S..; Eco-Architecture VII: Harmonisation Between Architecture and Nature
Account: ns335141

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Eco-Architecture VII

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S. Syngellakis
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Published by

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E-Mail: witpress@witpress.com
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Computational Mechanics International Inc
25 Bridge Street, Billerica, MA 01821, USA
Tel: 978 667 5841; Fax: 978 667 7582
E-Mail: infousa@witpress.com
http://www.witpress.com

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available
from the British Library

ISBN: 978-1-78466-301-8
eISBN: 978-1-78466-302-5
ISSN: 1746-4498 (print)
ISSN: 1743-3509 (on-line)

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Preface

This volume contains a selection of papers among those presented at the 7th International Conference on Harmonisation between Architecture and Nature, held in the New Forest, UK and organised by the Wessex Institute.

Eco-Architecture always aims at designs which adapt to the environment, learning from nature. Adopting traditional architectural concepts can help to achieve this, such as, for instance, a philosophy promoting harmonious equilibrium among nature, buildings and people or courtyards designed to perform as passive energy systems apart from serving the community's cultural needs. Several contributions in the volume highlight the importance of landscapes and green spaces. Mitigation strategies are identified against the adverse effects from industrial establishments; the spatial distribution of green spaces is evaluated from the point of view of health promotion; users' perception of open spaces is linked to their biophilic aspects.

Eco-Architecture is linked to sustainable or "green" design but the way this is realised is open to conflicting interpretations. A framework is here presented for structuring the various strategies that vary from technological innovation to empowering social action. One such strategy is the drive towards close resource loops whereby the impact of buildings and people on environment and climate change is minimised. New technologies can be used to optimise the management of resources throughout the lifetime of new or existing buildings. A case study assesses the resilience and sustainability of a residential project along the waterfront by exploring its siting, landscape, interior design and adopted technologies.

Eco-Architecture also promotes the idea of using the minimum amount of energy at each stage of the building process, including the amounts required during the extraction and transportation of materials, their fabrication, assembly, building erection, maintenance and eventual future recycling. New designs of modular buildings incorporating human and sustainable features can be quick to build but also easy to disassemble and transport. A case study explores the use of sycamore as structural material in a low energy building project; the structural performance and climatic adaptability of the material are assessed.

In order to predict the actual behaviour of dwellings during the design process, simulation tools need to be applied to assess their performance under various climatic conditions. A new computational technique is applied to the design of adaptable building facades aiming at the evaluation of day-lighting and heat gains performance of complex shape composites. A hygrothermal simulation package is used to predict the effects of wind-driven rain, radiation and temperature on ceramic

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tile facades.

The minimisation of energy consumption is one of the most important aspects of eco-architecture. Solar gain control through glazing, climatology and façade orientation, have to be carefully considered in architectural design. Integration of renewable energy generation into the building fabric is an objective that construction industry can achieve through collaborative procurement methods, building information modelling, innovation and energy positive buildings.

The papers presented at all Wessex Institute Conferences are archived in the Institute's eLibrary (witpress.com/elibrary) where they are available in open access format to the international community.

The Editor
The New Forest, 2018

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THE ENVIRONMENT AND *FENG SHUI* APPLICATION IN CHEONG FATT TZE MANSION, PENANG, MALAYSIA

AZIZI BAHAUDDIN & TEH BOON SOON
School of Housing, Building and Planning, Universiti Sains Malaysia, Penang, Malaysia

ABSTRACT
Feng Shui, literarily translated as wind and water, forms part of the Chinese traditional architecture theory. The philosophy aims to achieve harmonious equilibrium among nature, buildings and people. It continues to be used in dwelling site selections and layout of buildings as well as in the environmental planning, especially in the Form School *Feng Shui* school of thought. It focuses on site analysis, landscapes and building placements with emphasis on designing with nature and the environment. This *Feng Shui* approach can be traced in the building design of the *Peranakan* style architecture of Cheong Fatt Tze Mansion, a unique architecture in George Town, Penang. It is a mix of Chinese, Malay and colonial building styles. Unfortunately, this mansion has not been verified with the *Feng Shui* approach in relating the architecture with nature, despite a claim that was made of its application and for other buildings of the same style. This study addresses the cultural sensitivity of this architecture as a case study in embracing nature for its *Feng Shui* application. Qualitative analysis was employed to determine whether the design of this mansion corresponded well with favourable architectural conditions placed in the environment as stated in the Form School approach. The method applied included measured drawings, ethnography study of the *Peranakan* culture, interviews with identified *Feng Shui* masters and the mansion's owners. The mansion's architectural design conformed to the philosophy adapted from the Form School approach, especially in the architectural language. The conformity further addresses challenges and opportunities in pursuing the sustainable design approach based on the significance of *Feng Shui*, pertaining to the minimum use of energy and exploitation of natural ventilation and natural lighting. The *Feng Shui* Form School approach has significantly demonstrated the interrelationships between the architecture and the environment, specifically in this *Peranakan* architecture of Penang.
Keywords: Feng Shui, environment, Form School, Peranakan architecture.

1 INTRODUCTION

Feng Shui forms an integral part of traditional Chinese architecture theory. According to Lee [1], *Feng Shui* has been employed to aid in site selection for dwellings as well as building layouts. This timeless philosophy which emphasises harmonious relationships between man and nature is generally divided into two schools of thought known as the Form School and the Compass School [2]. While the latter focuses on astronomical factors and calculations, the former focuses on site analysis of landscapes. This study focuses on the Form School approach as it places emphasis on designing with nature and the environment. Furthermore, this approach has been recognised to have logical constrruction basis for use in building environment analysis [2], [3]. On closer inspection, the influence of the Form School *Feng Shui* approach can be identified in the design of *Peranakan* style architecture in George Town, Penang, Malaysia (Fig. 1); notably the Cheong Fatt Tze Mansion. In general, *Peranakan* architecture, also known as Straits Chinese architecture celebrates the confluence of Chinese, Malay as well as Javanese, Batak, Thai and European cultures in its design [4], [5]. Although Cheong Fatt Tze Mansion forms a unique cultural heritage with hybrid architectural style and Chinese influences, the adaptation of the *Feng Shui* Form School approach in the mansion's design and layout relating architecture with nature has yet to be verified. Furthermore, the principles of *Feng Shui* Form School approach have not been

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180011

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Figure 1: Penang and South-east Asia region [6].

studied together with the *Peranakan* architecture. Thus, this study addresses the cultural sensitivity of the *Peranakan* architecture through a case study of the Cheong Fatt Tze Mansion to understand how its architecture embraces nature for its *Feng Shui* application.

2 LITERATURE REVIEW

2.1 *Feng Shui*

According to Mills [7], *Feng Shui* is difficult to define due to its extensive history with various terms used to denote this theory throughout its development. Before the term *Feng Shui* was used, *Kan Yu* was one of the most commonly used terms. The term *Kan Yu* refers to observing the way of heaven and investigating the way of earth [8]. Today, according to Mills [7], the term *Feng Shui* is widely used to illustrate the theory as a form of art, science, a body of knowledge, a way of discerning the environment as well as superstition. However, *Feng Shui* scholars found that *Feng Shui* has reasonable logical value rather than mere superstitious [9]–[11]. In fact, *Feng Shui* which translates literally to “wind” (*Feng*) and “water” (*Shui*) is based on the examination of astronomical and natural phenomena as well as human behaviour [12]. While in the past, *Feng Shui* was used to determine the location of houses or graves [2], this theory is now continually used and explored as part of traditional Chinese architectural theory for site selection of dwellings and building layouts [1]. According to Mak and So [2], the practice of *Feng Shui* theory is divided into two schools of thought, influenced by the development and achievement of science, technology, architecture, philosophy, astronomy, medicine, culture and literature in China. The two schools of thought are the Form School and the Compass School [2]. The Form School, the older of the two focuses mainly on site analysis of landscapes while the Compass School is fundamentally governed by astronomical factors and calculations using *Luopan,* a *Feng Shui* compass [13]. As time progresses, principles of the Form School approach continue to form the core of *Feng Shui* practice even though new systems and criteria are established by contemporary *Feng Shui* practitioners [2], [3].

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2.2 The Form School

Contemporary *Feng Shui* scholars and researchers recognise the Form School approach as the most influential approach in analysing built environment [3], [14]–[17]. According to Skinner [13], He and Luo [18], design and construction of castles, palaces and towns in China have been using *Feng Shui* principles since ancient times. The Form School approach examines the physical surrounding of a site in order to identify the flow of *Qi*, believed to be the cosmic spirit giving life and energy to all things [13]. Based on *Zang Shu* (The Book of Burial) by Guo Pu, *Qi* can be moved by the wind (*Feng*) and collected in water (*Shui*) which are the two main elements in *Feng Shui* [19]. The basic observations in Form School approach are the form of mountains and hills, the flow of the water, and the relationship between hills and water. While there are different criteria being developed by contemporary *Feng Shui* scholars, the principles of the Form School approach still remain [2], [3]. Built upon various contemporary *Feng Shui* scholars' design criteria, Mak and Ng [3] and Mak and So [2] introduced the *Feng Shui* concept design criteria. In this paper, the *Feng Shui* concept design criteria were employed in the research as it adopts the principles and practices of Form School approach. Each of the criteria clearly specifies favourable and unfavourable conditions. This paper will focus on both the external and internal layout criteria to understand how the architecture of Cheong Fatt Tze Mansion of the *Peranakan* architecture embraces nature for its *Feng Shui* application (Table 1).

2.3 *Peranakan* architecture

Peranakan or Straits Chinese architectural style (Fig. 2) is influenced by the *Peranakan* culture born from the long history of the *Peranakan* or *Baba Nyonya* community who settled in the British Straits Settlement, known subsequently as Straits Chinese Settlement. Influenced by a confluence of Chinese, Malay, English and local cultures [20], the cultural practices of the *Peranakan* seeped into everyday life from language, food, daily apparels as well as the architecture throughout Malaysia especially in Penang and Malacca as well as in Singapore. Dwellings of the *Peranakan* in the maritime towns portray a fusion of European,

Table 1: *Feng Shui* concept design criteria [2].

Favourable Conditions for *Feng Shui* criteria	
Criteria	Condition
Front of the site	Level ground and open space in front.
Rear of the site	Back with mountain and building.
Sides of the site	Surrounded by buildings and plants.
Orientation	South and East facing.
Trees	Trees on the sides of building and on the West side.
Pond	Pond in front yard and close to building.
Layout	Kitchen on the perimeter.
Windows	South and East facing.
Unfavourable Conditions for *Feng Shui* criteria	
Criteria	Condition
Topography	Level.
Street Location	Corner of street.
Windows	North and West facing.

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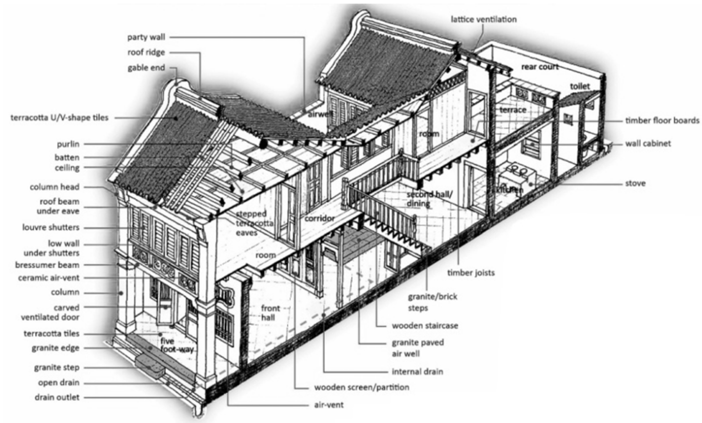

Figure 2: Sectional layout of a typical *Peranakan* shophouse [21]–[24].

Figure 3: Site surrounding of Cheong Fatt Tze Mansion.

Chinese and Malay influences which came to be known as "Chinese Baroque" architecture due to significant influences of Chinese and European building styles [4].

In terms of architectural language, *Peranakan* dwellings are symmetrical in their layout with the entrance located at the middle and windows flank both sides of the façade. On the exterior, typically a *ji-ho* – a Chinese inscribed signboard will be hung above the ornately carved entrance door known as the *pintu pagar* [4]. Wood carved ventilation openings with symbolic decorations are also common exterior features [5]. *Peranakan* architecture's internal layout is generally made up of a reception hall, an ancestral hall, kitchen, bedrooms as well as introduction of an air well or courtyard in bigger homes. A significant characteristic of *Peranakan* architecture, the introduction of air wells in the centre of dwellings is reminiscent of Chinese courtyard houses and affords enhanced ventilation and interior day lighting into the usually deep plan of shophouses (Fig. 3) [4].

3 METHODOLOGY

The ethnography study of *Peranakan* culture was undertaken with Cheong Fatt Tze Mansion selected as the case study. To understand the Form School *Feng Shui* approach in the design of this mansion, the design criteria developed by Mak and Ng [3] and Mak and So [2] was adopted in this study. Interviews with the mansion's owners were undertaken during the site visit. After the site visit, a qualitative analysis using measured drawings were employed to determine whether the design of the Cheong Fatt Tze Mansion corresponded well with

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favourable architectural conditions placed in the environment as stated in the Form School approach. Findings were then confirmed through interviews with identified *Feng Shui* masters.

3.1 Ethnography study

The culture of the Baba-Nyonya is strongly embedded in this architecture. It depicts a blend of many cultures of Malaysia, a blend of the Chinese culture brought in from the mainland; the British colonial influence that was imported from England as well as the Malay cultural elements that can be observed in the tropical architectural components.

3.2 Cheong Fatt Tze Mansion

Cheong Fatt Tze Mansion, also widely known as the Blue Mansion was built by the Chinese immigrant merchant Cheong Fatt Tze at the end of the 19th century [22]. The mansion is famous for its opulence and eclectic architectural elements as well as *Feng Shui* application. According to Loh-Lim [23], its architecture demonstrates Cheong Fatt Tze's captivation with western artisanship and his rising significance as a Chinese official and reflects both national and regional influences with a distinct mixture of materials, motifs, decorative style as well as architectural language.

3.2.1 Architectural elements of Cheong Fatt Tze Mansion

Cheong Fatt Tze Mansion is an example of an eclectic mix of styles with contrasting elements such as Scottish cast-iron balusters with Cantonese timber lattices as well as English Art Nouveau stained glass windows with Hokkien "*Chien Nien*" (cut and paste shard works) (Figs 4–7) [23]. The architectural elements of the Cheong Fatt Tze Mansion are summarised in Table 2.

3.2.2 *Feng Shui* application

According to Dijk [25], Cheong Fatt Tze Mansion has been noted as a dwelling with perfect *Feng Shui* by geomancers. It was recorded that the mansion was built under the supervision of some of the best *Feng Shui* experts of the period [26]. Nevertheless, while there were few elements of *Feng Shui* identified by Skinner [26] and Loh-Lim [23] (Table 3), the identified *Feng Shui* elements were not clearly defined and classified into the two different schools of thought. Apart from that, most of the identified elements were found to be related to the Compass School. This study thus looks into the application of Form School approach in the Cheong Fatt Tze Mansion.

3.2.3 Cheong Fatt Tze as a case study

There were two reasons Cheong Fatt Tze was chosen as the case study. Firstly, the characteristics of the mansion such as architectural style, exterior and interior features, reflect those of *Peranakan* architecture as shown in Table 4. Secondly, the application of *Feng Shui* was recorded during the construction of the mansion.

4 FINDINGS

In general, while the layout of the mansion was built based on the Form School approach to *Feng Shui*, the façade design as well as materials and detailing of the mansion adhered to *Peranakan* Architecture characteristics with its eclectic mix of exterior and interior features as described in Table 4. As rather than concentrating on the overall stylistic characteristics

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Figure 4: Terracotta roof tiles and decorative mosaic porcelain.

Figure 5: Timber filigree carvings and coloured tiles.

Figure 6: Victorian Scottish cast-iron columns and railings.

Figure 7: Stained glass panels.

Table 2: Architectural elements of Cheong Fatt Tze Mansion [24].

Architectural Elements	Description
Roof	Terracotta roof tiles.
Timberworks	Timber filigree carvings, teak beams, solid paneled doors with craved architraves and timber louvered windows.
Ironworks on balustrades, columns and spiral stairs	Victorian Scottish cast-iron columns and railings.
Stained glass windows	48 Art Nouveau stained glass panels.
Decorative paintings	On gables of the buildings, beams border at the main courtyard, and internal walls.
Decorative mosaic porcelain works	Porcelain works with elaborate patterns of men, women, animals and sceneries depicting Chinese mythology.
Plaster and paint	Lime plaster and lime wash paint.
Tiles	Coloured tiles imported from Stoke-on-Trent in Staffordshire, England.

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Table 3: Identified *Feng Shui* elements in Cheong Fatt Tze Mansion [13], [23].

Identified *Feng Shui* elements in Cheong Fatt Tze
1. Orientation of the building unparalleled to Leith Street. 2. Five Courtyards. 3. Drainage System. 4. Three bays wide as odd number considered as Heaven numbers. 5. Gold coins buried at strategic place. 6. Period of construction.

Table 4: Characteristics of *Peranakan* architecture and Cheong Fatt Tze Mansion [24].

Characteristic	*Peranakan* Architecture	Cheong Fatt Tze Mansion
Architectural style	A mixture of Chinese, Malay, Batak, Thai and European elements.	A mixture of Chinese, Malay and European elements.
Exterior features	Symmetrical organisation.	Symmetrical organisation.
	Five-foot walkway at the front of the building.	Five-foot walkway at the front of the building.
	Security bars on windows.	Security bars on windows.
	Gable and pitch roofs.	Gable and pitch roofs.
Interior features	Cast iron for the pillars and balcony balustrade.	Victorian Scottish cast-iron columns and railings.
	Coloured tiles from all periods: Victorian, Edwardian, Art Nouveau, Art Deco, 1950s and 60s pop art.	Coloured tiles imported from Stoke-on-Trent in Staffordshire, England.
	Air well.	Five air wells.
	Plaster ceiling ornaments.	Plaster ceiling with decorative works in the form of peonies and gold butterflies in the corners.
	Ventilation opening or partition was carved in wood with decoration.	Timber partition between main hall and central courtyard was carved in wood with decoration.
	The front hall or sitting area functioned as reception hall while the dining room; rear verandah and side rooms are the private family area.	The main hall functioned as reception hall while the dining room, rear verandah, and side rooms are the private family area.
	Antique furniture.	Antique furniture.

of buildings, the Form School approach focuses mainly on the overall setting, orientation and space planning of the mansion. Thus, findings of this research reveal that the mansion's architectural design conformed mostly to favourable conditions adopted from the Form School approach, especially in its external and internal layout. Table 5 depicts findings of favourable criteria while Table 6 shows the unfavourable criteria as well as a solution to mitigate the situation. It is imperative to say that the architecture of the Cheong Fatt Tze Mansion although is seen as applying the traditional beliefs of *Feng Shui*, the building has exhibited its agreement with nature to strengthen the understanding of *Feng Shui* of having practical applications in this architecture. The favourable conditions have allowed the

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Table 5: Favourable conditions for *Feng Shui* criteria in Cheong Fatt Tze Mansion.

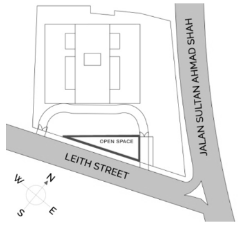
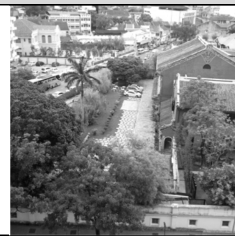
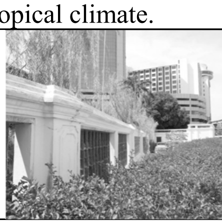
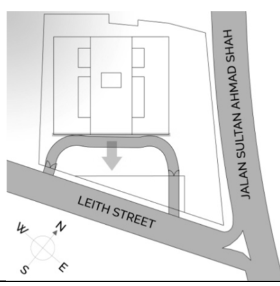
<table>
<tr><th>Feng Shui criteria</th><th colspan="2">Diagrams</th></tr>
<tr><td rowspan="2"><u>Front of the site:</u>
Level ground and open space in front.</td><td>Site plan 
</td><td></td></tr>
<tr><td colspan="2">The mansion’s main entrance fronts a level ground with a big open lawn, conforming to favourable conditions of the form school criteria. Coupled with the front windows and air wells in the mansion, this configuration encourages cross ventilation into the interiors effectively.</td></tr>
<tr><td rowspan="2"><u>Rear of the site:</u>
Backed by mountain and building.</td><td colspan="2"></td></tr>
<tr><td colspan="2">A favourable condition prescribed by the form school approach is to have the rear of the mansion backed by mountain (Penang hill) and buildings. The mansion is seen to conform favourable to this criteria which provided shade and reduced the exposure of the rear to the hot sunlight of the tropical climate.</td></tr>
<tr><td><u>Sides of the site:</u>
Surrounded by buildings and plants.</td><td> </td><td>There were buildings and plants on both sides of the mansion, which shaded the exterior façade of the mansion from the direct east–west sun exposure, thus lowering down the surrounding temperature.</td></tr>
<tr><td rowspan="2"><u>Orientation:</u>
Facing South and Facing East.</td><td>Site plan

</td><td></td></tr>
<tr><td colspan="2">The mansion’s front façade orientates towards South and East conforming to the favourable conditions, minimising impact of the hot evening sunlight into the internal spaces within the building.</td></tr>
</table>

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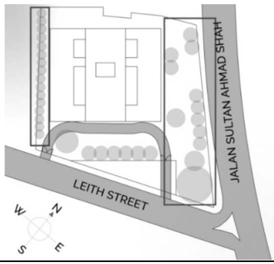
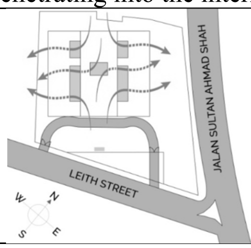
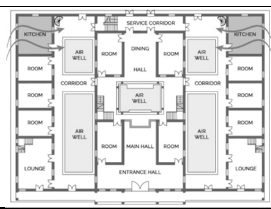
Table 5: Continued.

<table>
<tr><th>Feng Shui criteria</th><th colspan="2">Diagrams</th></tr>
<tr><td rowspan="2"><u>Trees:</u>
Trees on the sides of the building and on the West side.</td><td>Site plan

</td><td></td></tr>
<tr><td colspan="2">There were trees at the front and on both sides of the mansion including the West, which helped in reducing heat from the morning and evening sunlight from penetrating into the internal spaces of the mansion.</td></tr>
<tr><td rowspan="2"><u>Pond:</u>
Pond in front yard and pond close to building.</td><td>

Site plan</td><td>
</td></tr>
<tr><td colspan="2">Water features were evident at the front yard and courtyards, reducing temperature of the surrounding site. Openings at courtyards encourage natural ventilation and natural lighting into internal spaces of the mansion.</td></tr>
<tr><td rowspan="2"><u>Layout:</u>
Kitchen on the perimeter area.</td><td colspan="2">

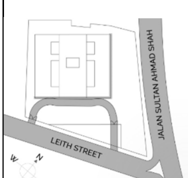
Ground floor plan</td></tr>
<tr><td colspan="2">Apart from segregating the services area from the public area, the two kitchens located at the perimeter area towards the rear of the mansion encourages and maximizes natural ventilation and natural daylight which is crucial for service areas.</td></tr>
<tr><td rowspan="2"><u>Windows:</u>
Facing South and Facing East.</td><td>Site plan

</td><td></td></tr>
<tr><td colspan="2">The mansion had windows located at the South and East as recommended in Feng Shui as the location of the windows are able to minimize the hot evening sunlight while maximizing daylight into the internal spaces.</td></tr>
</table>

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Table 6: Unfavourable conditions for *Feng Shui* criteria in Cheong Fatt Tze Mansion external and internal layout.

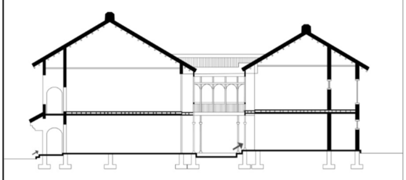
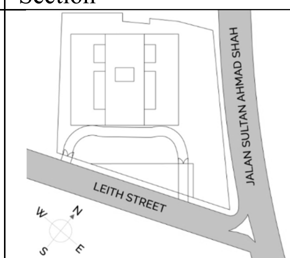
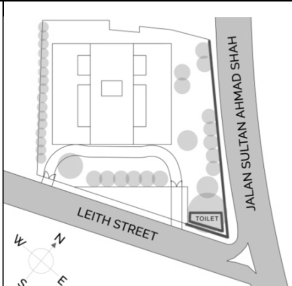
Feng Shui criteria	Diagrams
<u>Topography:</u> Level	 While a level ground in front the mansion is considered favourable, topography wise, a level ground for the whole mansion layout is considered unfavourable. One of the reasons may be due to the possibility of flooding from the surrounding into the interior spaces.
Solution	 Section As a solution to the unfavourable existing topography level, the mansion introduced steps up from the front lawn into a portico before entering the main entrance of the mansion.
<u>Street Location:</u> Corner of streets	 Site plan In terms of location, for a building to be located at the corner of the streets are considered unfavourable. This condition may be due to noise and air pollution, especially at street intersections.
Solution	 Site plan  High perimeter wall  Toilet area While the mansion is located at a corner between two streets, to counter this unfavourable condition, high perimeter walls were erected along the perimeter of the two streets. In addition, the mansion was set back significantly from the streets and injected greeneries as well as service area on either of these two perimeters.

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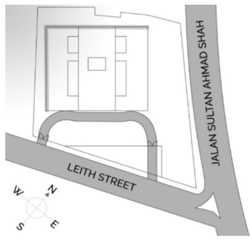
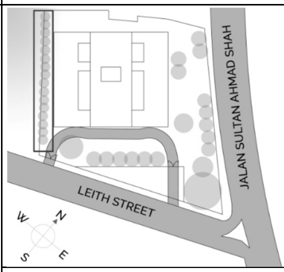
Table 6: Continued.

Feng Shui criteria	Diagrams	
Windows: Facing North Facing West	 Site plan	Orientation of windows on the façade to the North and West are under unfavourable conditions as internal spaces would be more exposed the hot evening sunlight.
Solution	Site plan 	
	Although the mansion had windows on both the North and West façade, this unfavourable condition was mitigated by having the area facing towards North and West planted with landscape, which also acted as shading for the mansion.	

building to withstand the elements through the understanding of designing and applying the right architectural components to agree with nature. Rather than fighting against the environment, it was built according to the requirements of the surroundings. These findings allow the researcher to look further into establishing a formal checklist for ensuring that similar buildings have all the required components to establish a link between *Feng Shui* and nature.

5 CONCLUSION

With interview verification of the findings from *Feng Shui* masters, this study illustrates that Cheong Fatt Tze Mansion with its opulent *Peranakan* architecture conforms to the external and internal *Feng Shui* layout criteria by Mak and Ng [3] and Mak and So [2]. Besides, the findings also demonstrate how the architecture of Cheong Fatt Tze Mansion embraces nature through its *Feng Shui* application, optimising both natural ventilation and daylighting while reducing solar heat gain through its orientation and landscape features. This conformity further addresses challenges and opportunities in pursuing the sustainable design approach based on the significance of *Feng Shui*, pertaining to the minimum use of energy and exploitation of natural ventilation and natural lighting. The *Feng Shui* Form School approach has significantly demonstrated the interrelationships between the architecture and the environment specifically in this *Peranakan* architecture of Penang. Findings from this study can be used as a stepping-stone to inform designers, cultural researchers as well as heritage conservationists in the application of Form School *Feng Shui* in *Peranakan* architecture as well as a way to build in harmony with the environment.

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ACKNOWLEDGEMENTS
The authors would like to acknowledge the Universiti Sains Malaysia for the support under the USM Fellowship and funding this research under the USM University Research Grant Individual (RUi) 1001/PPBGN/8016011. The authors would also like to acknowledge the School of Housing, Building and Planning, Universiti Sains Malaysia for the project.

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ECO-TRADITIONAL COURTYARD HOUSES IN UAE: A CASE STUDY OF THE SHARJAH MUSEUMS

IMAN IBRAHIM
Architecture and Interior Design, University of Sharjah, UAE

ABSTRACT
A courtyard is an architectural design element traditionally and commonly integrated in UAE vernacular architecture for its environmental and social potential that reflects the sustainable design bases in traditional architecture. This research provides a qualitative study on the usefulness of courtyards as passive energy saving systems in the UAE. This includes my investigation into traditional old houses in Sharjah, to compare their courtyards' traditional use with the recent use of these courtyards after renovations and the changes in functions of some houses that currently are used as art exhibitions or museums. The research purpose is to focus on the application of courtyards in the context of the Heart of Sharjah public buildings, that reused the internal courtyards spaces for various community activities to create a socially active hub, to represent the cultural and traditional aspects for the Emirates community and its recognizable character, that express the community's cultural needs and extend the communication roots by introducing some historical background to new generations. The aim is also to raise awareness of the potential environmental aspects of courtyards in the hot dry climate of the UAE, with respect to the vision of sustainable architecture that reflects the natural context, including the climate conditions, the human context, and traditional cultural values. In addition, the research investigates the strength of the relation between the well-designed courtyard and its occupants' social behavior: the social aspects of sustainability traditionally and recently as well. The research study is qualitative and based on interviews, surveys and technical measurements that targeted public visitors to the selected buildings as a case study. The results from the analytical part of the research, including a list of recommendations to be applied to the traditional houses in Sharjah for their renovation and preparation for public use in terms of the cultural building principles that match the traditional and environmental aspects of sustainability.
Keywords: traditional architecture, courtyard house, Sharjah heart, sustainability.

1 INTRODUCTION

The research methodology involves qualitative analysis for the selected old traditional houses in Sharjah that integrates theoretical models with empirical ones that test the appropriateness of the research hypotheses of sustainability potentials in traditional architecture in the UAE, and Sharjah Emirate in particular.

The growing concern for traditional architecture and historical buildings is part of the global concern to preserve the heritage. Previous research highlighted the importance of traditional architecture, and its connection to the wider view for sustainability. That was clear in previous definitions for traditional architecture which as Kennedy stated is "An architecture style that develops from the particular climate and social conditions of a place" [1]. Another definition was given by Rashed Bukhash who considered that traditional architecture contains many values of peoples' lifestyles in an area and translates their needs in a unique character [2]. The research in this paper considered all previous definitions of traditional architecture, and so claims that traditional architecture is related to sustainability, as both consist of social, environmental and economic potentials

"Yet, to the Arab especially, the courtyard is more than just an architecture device for obtaining privacy and protection. It is, like the dome, part of a microcosm that parallels the order of the universe itself." Hassan Fathy inspired many architects by these words giving the courtyard a special deep concept to the Arab world architecture [3].

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180021

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The courtyard house was a common architectural expression in many civilizations, and continues to be in the Arab countries as part of their vernacular architecture. The research claims that the courtyard is a unique dominant element that exists in most of vernacular architecture types in the Arab world's traditional architecture. The hot, arid climate of the Middle East was one of the driving forces in adopting courtyards into the architectural vernacular. The courtyard allowed builders to temper the climate indoors by affecting the wind, humidity, and sunlight. Another important driving force for the prominence of courtyards in the Middle East is the social aspects attached to an open central space.

2 THE COURTYARD CONCEPT AND SUSTAINABILITY

The courtyard house plan type existed throughout the world centuries ago. It became a prototype in urban design strategies for the hot arid zones. In addition to a functional, important role for climate control in the courtyard house, a traditional cultural relevance of importance in Arab countries, this type of architecture proved to have efficient purposes.

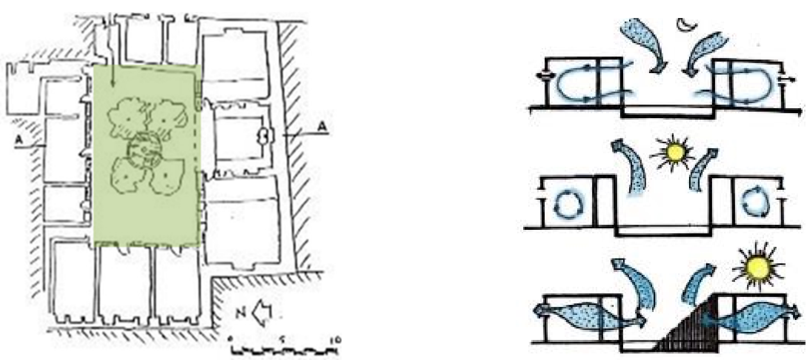
Courtyards as a prototype plan have two basic components: to respect and to accommodate the climate as the environmental aspect of sustainability, since the major function for the courtyard is to control the environment and to maintain suitable weather for the humans, as well as to create an inner environment, that provides privacy and solitude environment. The second aspect is the social one that includes Islamic and cultural fundamentals that have to be considered, and to reflect the social aspect of sustainability.

The research demonstrates that the courtyards' design is an essential part of the vernacular traditional architecture. It serves the principles of sustainability as a multi-dimensional concept that includes economic, social and environmental dimensions.

2.1 Courtyard climate study

The demands of a hot climate led to a number of design characteristics. A courtyard is a well-recognized one that has been used for many centuries in houses, schools, mosques and government buildings.

The climate of Arab countries, and the UAE generally is very hot and sunny. The hottest months are July and August, when average maximum temperatures reach above 50°C (122.0°F) on the coastal plain, a result of increased altitude. Average minimum temperatures



(a) (b)

Figure 1: A sketch of a courtyard house. (a) Plan drawing; (b) Air circulation between courtyard and adjoining rooms at night, midday and afternoon [5].

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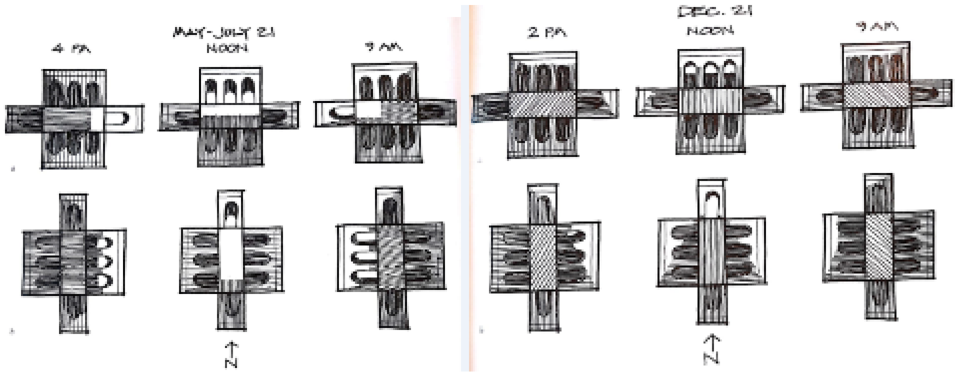

Figure 2: A sketch to show the amount of shade in the courtyard during the year at different times of the day [6].

in January and February are between 10 and 14°C (50.0 and 57.2°F) [4]. In hot arid zones, use observe narrow streets in urban areas to shade them from the sun, and low rise buildings with an inner courtyard.

Regarding climate, there were three main design factors to consider, insolation, wind and humidity, where most of the studies in the hot arid zones vernacular architecture proved that correct orientation required the designer to study the movement of the sun in summer and winter and in relation to plans and sectional arrangements. It was important to ensure that sunshine was beneficial without the harmful effects of excessive temperatures and glare [5].

Environmentally, a courtyard is a thermal regulator, a small space in the middle of the house surrounded by rooms with different functions connecting them together providing shade and cool because of the surrounding high walls. The cool night air fills the courtyard and the surrounding rooms from the late afternoon time until the sun rises directly in the courtyard where the structure acts like a chimney.

The orientation of courtyards used to be designed to be parallel to the street outside. In most cases the shape of the courtyard is rectangular, that determines the amount of shade provided through the year to the courtyard as well the amount of light provided to the rooms attached to the courtyard, as shown in Fig. 2, a typical proportion for the rooms that face the courtyard ideally are wider along the courtyard than they are deep, to guarantee that the daylight from the courtyard can fill the room more evenly [6].

2.2 Courtyard social cultural aspects

The harsh environment in the Arab world affected the houses' design, but other social aspects, such as privacy, were also the main reasons leading to the use of the courtyard in the Arab houses bringing spiritual, functional and climate benefits to the design. With great influence of the Islamic religion, the importance of the courtyard increased as it gives privacy to the family, where the courtyards were used to separate the public domain from the private domain [6].

The courtyards affect the zoning of the house and the organization of spaces with its functions, beginning with the first transition from heat, noise and glare from the street to the cool dark quiet covered entrance to the courtyard. The second transition is the passage through the cool shaded courtyard with some day light, while the last transition is the entrance

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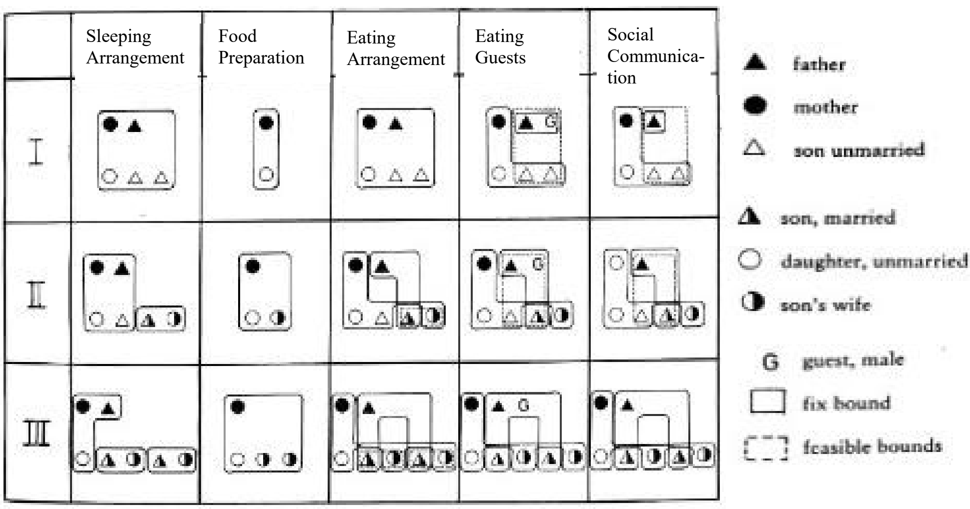
to the private rooms of the house. Islamic religion affected the house zoning distribution beyond the family members and the space functions, and the courtyard played a principal role in this distribution. Table 1 shows each space function and who of the family members are allowed to occupy this space.

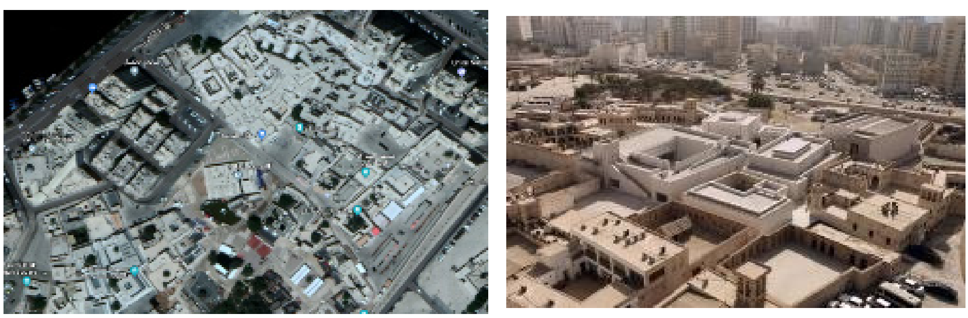
3 COURTYARDS IN SHARJAH VERNACULAR ARCHITECTURE

Sharjah vernacular architecture corresponded extremely effectively to environmental conditions and social values. The design of residential houses depended on privacy principles as the private spaces opened to an internal open courtyard to provide privacy and isolation.

External elevations were massive and almost solid to protect the inner environment from the harsh climate outside, some small opening appeared in the first floor in repetitive sequences. The urban design is compact and all houses are beside one another, opening onto narrow shaded streets, that provide climate protection [7].

Table 1: A diagram showing the typical grouping of family members for each task. *(Source: Friedrich, 2003.)*





(a) (b)

Figure 3: The layout for old Sharjah heritage area, UAE. (a) Top view; (b) Perspective view of some old houses with inner courtyard. *(Source: Authors, 2017.)*

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3.1 Sharjah museums

The Emirate of Sharjah is a pioneer in the creation of museum infrastructure in the Gulf States [8]. Sharjah Heritage area is a clear example of vernacular architecture in Sharjah, that consists of two tiny neighborhoods, Al Sheyoukh and Al Maraija. There are a number of old traditional Emirati houses that were converted into museums under the umbrella of the Sharjah Heritage Museum; they are linked to the traditional Souq there [9].

What characterizes the heritage area of Sharjah is the traditional activities that express the community's cultural needs and extend the communication roots to introduce historical backgrounds to the new generations, in other words it extends the social sustainability within the Sharjah community. In addition, introducing international events and exhibitions, such as the Sharjah Biennial gives a strong indication of the importance of the community-based hub of the Emirati social life that aims to increase awareness of UAE nationals with their heritage and culture.

The concept of the preservation of old houses in Sharjah to change their function into museums adds value to Sharjah vernacular architecture, as it's noted that these museums become a culture hub internationally, as when they host international art festivals, like Sharjah Biennale, that last for many years. The research covered the urban design for the Sharjah heritage area, and recorded the main museums that were old residential houses before with courtyards, that changed their functions to be social community activities' focal points.

3.2 Sharjah museums courtyards social activities

One of the most unique old houses in Sharjah is Bait Al Naboudah (House of Naboudah). This house originally belonged to the late Obaid bin Eissa Bin Ali Al Shamsi, nicknamed Al Naboodah. He was a prominent pearl merchant who held commercial ties with India, Africa and France. Al Naboodah lived in this house, which was built in around 1845, with his three wives and children. The construction of the house went through several phases as his family grew [10].

The house has two stories, and was built around a large courtyard, and the walls made of light coral construction material. Bait Al Naboodah is considered a traditional local prototype house that respected design elements and cultural values, as the function distributed to follow the local social life where we find the Male Majlis beside the entrance in the ground floor near to the kitchen and the guest rooms, the Liwan that separate the public domain from the

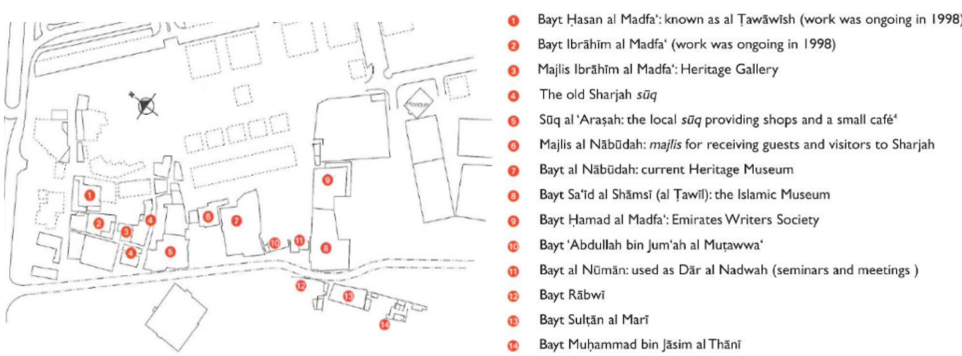

Figure 4: The layout for Sharjah heritage area museums, UAE. *(Source: Friedrich, 2003.)*

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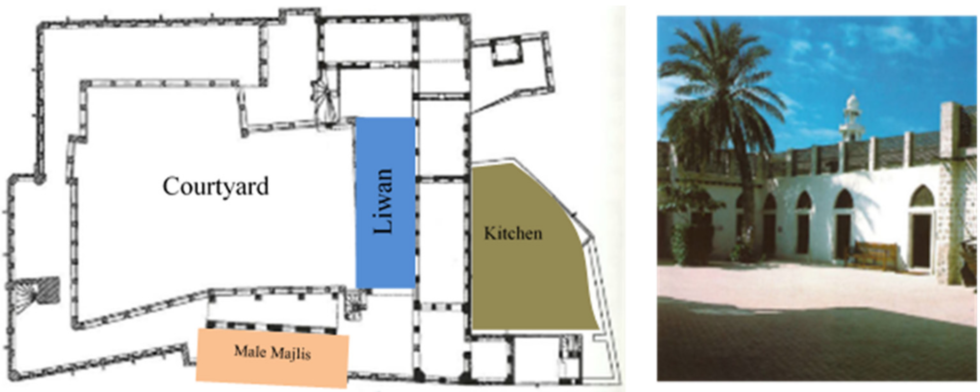
open courtyard where the private domain starts, and all private family rooms in the first floor [7].

The main function of the traditional building envelope is to protect the building from the extremely hot climate outside. The materials selected are from the area itself. Brick, stone, palm trunks, and wood, and all of these local materials are recyclable and energy efficient. They act as thermal insulation by being used to build thick walls [11].

Most of the rooms are used as display rooms for UAE local's social life collections, and the unique element is the courtyard house where the Sharjah Museums Authority hosts many cultural tourist events and community celebrations and gatherings [10].



(a) (b)

Figure 5: Bait Al Naboudah in Sharjah, UAE. (a) Plan drawing; and (b) Internal view of the inner courtyard. *(Source: Friedrich, 2003.)*

(a) (b)

Figure 6: Bait Al Naboudah's courtyard house in Sharjah, UAE. (a) Day activity in the courtyard; and (b) Night activity for the community in the courtyard. *(Source: Authors, 2017.)*

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3.3 Sharjah museums: the model

During the month of August, 2017, the author interviewed 16 people in pilot interviews. The people interviewed were UAE locals aged from 18 to 40 years old, they came from different backgrounds and lived in different Emirates. The author also interviewed two expatriates who had been living in the United Arab Emirates for the past 10 years.

All of the visitors agreed that they were impressed to visit genuine traditional houses that had been restored as museums. The issues that gave the visitors two different experiences were the history of the vernacular architecture of UAE and the valuable exhibits. The second point in the interviews was the courtyard as a unique thermal system that still works efficiently. They felt the immediate change in temperature once they entered the courtyard.

The model of Sharjah museums highlighted the importance to realize the value of traditional architecture in the UAE with regard to sustainability in vernacular architecture. Restoration, preservation and rehabilitation are significant for old houses in Sharjah to be viable museums that might change the concept that ties traditional architecture in Arab countries with poverty, instead of the superior vision for the implemented western modern architecture.

4 VERNACULAR ARCHITECTURE INFLUENCE IN SUSTAINABILITY

Sustainability has a multifaceted nature that cannot be adequately defined nor understood through the tools available in any single discipline. Rather it must be considered from several disciplinary perspectives. The research adopted the Burtland definition of sustainability, where it was clearly defined by the World Commission on Environment and Development in the Brundland report, as: "The development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [12].

For many years, the concept of sustainability was limited to the environmental aspect as standalone pillar, but later on, most of the researchers agreed on the three-dimensional model of sustainability with its three pillars, environmental, economic and social. The research argues that these pillars' importance ratios vary from one community to another, as in some communities that have old traditions, social/cultural customs as in Arab communities, the social pillar has more influence. These differences need to be considered in attempts to reach sustainability.

Surveying the three pillars of sustainability in vernacular architecture in Sharjah, it was clear that the environmental pillar was important in order (as stated above) to protect from the harsh climate using the passive energy strategies by the use of natural and renewal resources: using the courtyard houses in residential old houses that utilize natural resources, sun and wind access, for example, as components of healthy comfortable spaces for the inhabitants. Also considering the basic principles of society values in the Emirates' communities, it is necessary to respect the social pillar of sustainability, achieved by traditional houses in Sharjah, as mentioned before in Bait Al Naboudah, in the example that highlighs the social role for the courtyard.

The experience of changing the function of traditional houses in Sharjah into public museums enriches the community's culture with vernacular architecture and people's identity, traditions and heritage as well, as applied in 19 museums in Sharjah that were old residential houses.

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4.1 Social sustainability in vernacular architecture

The principles of social sustainability are designed to meet the goals of socially sustainable communities and to this end, are aspirational and visionary statements that describe what makes a community healthy and liveable, both now and in the future [13], where the principles of sustainability are tied to each community and varied in the application.

4.1.1 Equity

The community provides equitable opportunities and outcomes for all its members, particularly the poorest and most vulnerable members of the community. While equity is listed as a separate principle, it is such a fundamental component that it can't really be separated from the other principles. The concept of vernacular architecture is to fulfill the community's social and cultural needs that guarantee equity to all inhabitants, and this was clearly illustrated in the design of Sharjah's old houses, where we find clear zoning distribution based on space function and segregation principles, where we can find male zones (Majlis) near the entrance as a public domain providing privacy to female members of the family in the house, as well the design to isolate the servants in the kitchen area near the guests' rooms. All of these considerations increase local family social cohesion [14].

4.1.2 Diversity

The community promotes and encourages diversity. The vernacular architecture provided various types of residential houses to fulfill each community's social needs, even in the same country, in local communities the house designs varied from one emirate to another [12], but the courtyard was the main element in design of all types in different emirates.

4.1.3 Interconnectedness

The community provides processes, systems and structures that promote connectedness within and outside the community at the formal, informal and institutional level; that is what

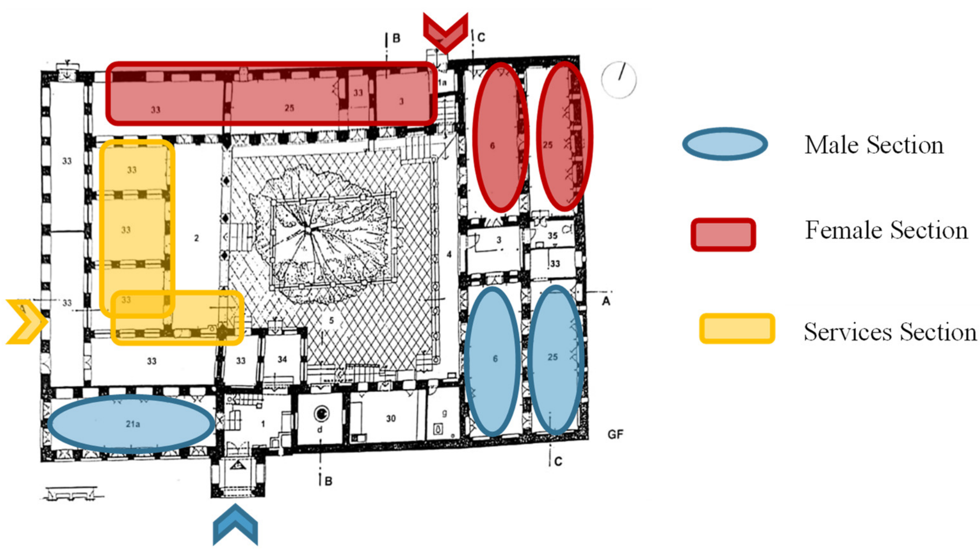

Figure 7: A traditional prototype house showing the different zones with entrances for family members and guests [14].

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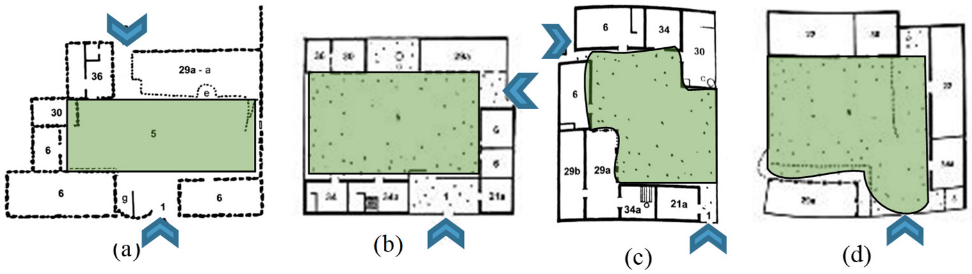

Figure 8: Various types of traditional houses in UAE. (a) Wadi Al Sham courtyard house; (b) Al Shamel house with entrance leads to male Majlis; (c) Rams house with two opposite entrances; and (d) Ras Al Khaima house with courtyard screen division [6].

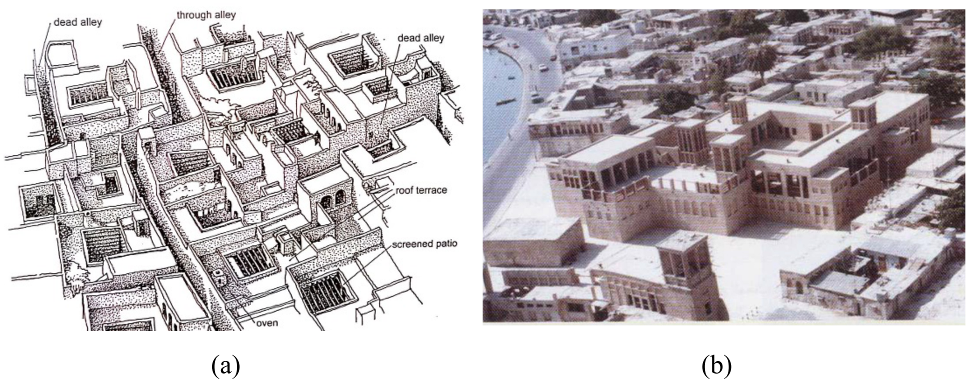

Figure 9: Old traditional houses compact urban planning of UAE. (a) Sketch of old houses planning; and (b) Old Dubai urban design. *(Source: Friedrich, 2003.)*

vernacular architecture aims to do. As shown in Fig. 6, the distribution zones in the traditional house plan insure the family ties and the right of each family member to have privacy and to welcome their own guests without interruption to the rest of family members. These are some of the social processes that promote connectedness.

4.1.4 Quality of life
The community ensures that basic needs are met and fosters a good quality of life for all members at the individual, group and community level. That's clear on both levels of vernacular architecture, houses and urban planning for neighborhoods in UAE, where the design of local house ensures fulfilling all family members social needs that enrich the sense of belonging and safety, as well the compact design for the houses that create shadow streets which, in turn, enrich the community relationships and the relationship with the surrounding nature.

In the 21st century, architects are expected to be more creative and well aware with the impact of their designs to the environment and nature as well. In this respect, we can get guidance from traditional vernacular architecture and learn lessons for creating designs that

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are responsive to climate conditions, to the social aspects that fulfil the community requirements related to social culture definitions and values, and to economic aspects that will affect building materials selection which is made from the local environment thus responding to the climate and surrounding environmental aspects.

4.1.5 Democracy and governance

The community provides democratic processes and open and accountable governance structures. As mentioned before, vernacular architecture give a clear example in fulfilling the community social needs that gives the community members the sense of belonging leading to transparent social systems enriching the democracy as a life style for such socially sustainable communities.

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LANDSCAPE COMPATIBILITY OF FACTORIES: FROM PRACTICES TO TACTICS

LIA MARCHI[1], ERNESTO ANTONINI[1] & STEVE EVANS[2]
[1]Department of Architecture, University of Bologna, Italy
[2]Institute for Manufacturing, University of Cambridge, UK

ABSTRACT

Industrial facilities are responsible for several detrimental effects on the landscape. Impact occurs in terms of both interference in the main ecosystem's physical matrices and intense perceptual-aesthetic contrasts with the landscape. As a result, the social sphere also is affected and corporate identity is threatened. Agri-food companies are particularly touched by the issue due to the high environmental impact of their processes, their recurring proximity to the rural landscape, and the strong link between corporate image and environmental attitude. Since the Eighties, literature and regulations have proved harmonisation between industry and landscape is a crucial element of companies' social awareness. In this framework, some tools have been developed to analyse the impacts, but their main focus is on environmental issues. Nowadays there is no unitary vision capable of balancing manufacturing requirements with effective measures to mitigate the impact of factories on the landscape at all different levels. Our research therefore aims to define a methodology to analyse how agri-food facilities interfere with the landscape and to develop a set of measures suitable to promote less conflictual relationships. This can be achieved by combining the natural, perceptual-aesthetic and social/cultural dimensions of landscape. The goal is to develop a design support tool to analyse impacts and prioritise weaknesses, thereby helping companies to define case-specific mitigation strategies. In particular, the paper presents real life case studies noteworthy for the adoption of mitigation practices, from which a set of general tactics was devised. Over 50 exemplary facilities have been analysed, 200 good practices identified, and more than 100 general mitigation tactics formulated. Furthermore, the study has identified recurrent patterns in the architecture of factories, which generally confirm trends found in literature.
Keywords: environmental impact, landscape harmony, factories, corporate identity, mitigation tactics.

1 INTRODUCTION

Decades of shallow practices in the design of factory now call for a deep reflection on the relationship between industrial sites and the everyday landscape. Over the last forty years academics, policymakers, companies and consumers have become increasingly interested in the topic, and several design support tools have been developed with the aim of reducing the impact of industrial facilities on the landscape. However, a unitary and consistent approach to cope with the manifold dimensions of the problem is still lacking.

The paper presents some outcomes of a research project which aims to define a methodology to analyse and ideally enhance the landscape compatibility of factories by dealing with their environmental impact, aesthetic-perceptual interference and the related socio-economic aspects. An overview of the general assumptions and approaches adopted in the study is presented and the main findings of the first research stages are described. Specifically, the article discusses the structured analysis of selected case studies, which led to the identification of mitigation practices, and the extraction of an inventory of impact reduction tactics.

2 IMPACT OF FACTORIES ON THE LANDSCAPE

Industrial facilities significantly interfere with the landscape. In this framework, a clear definition of the terms and boundaries is needed, as landscape is a broad and multifaceted concept which has often been confused with environment [1]. This research assumes the

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180031

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definition of landscape given by the European Landscape Convention (ELC) [2]: an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors. Accordingly, the landscape components set by the Landscape Character Assessment [3] have been adopted (Fig. 1). Thus, the impact of industrial facilities on the landscape is not limited to its natural dimension, but the perceptual-aesthetic and cultural/social components also need to be considered.

Firstly, factories affect the natural component of the landscape. Industrial facilities, in fact, often compromise the quality and balance of the urban or rural ecosystems that host them. This is due to their high energy consumption, intense use of natural resources and harmful emissions on the main environmental physical matrices [4], [5], typically caused by manufacturing processes, facility construction and operations, and heavy traffic flows.

Secondly, beyond their physical impact, they also create perceptual-aesthetic disturbances, disrupting the quality of the everyday landscape. An analysis performed in the Mediterranean regions [6] shows that in general factories are scattered in a disorderly manner throughout the territory due to ineffective planning rules or mere company attitudes. In addition, the study highlights that attention to the aesthetic quality of productive facilities is usually scarce. As a matter of fact, industrial buildings often lack spatial associations with the context, figurative identity and design quality [7], [8]. Since factories are rarely harmoniously integrated into their surroundings, they are rather perceived as landscape detractors [9].

Lastly, the social sphere also is affected: since the ELC recognises the landscape as a ground for collective memories and natural, cultural and symbolic associations [6], [10], its quality plays a key role in the well-being of individuals and society [11], [12]. Consequently, spatial proximity to a badly designed factory can affect the nearby communities, engendering negative psychophysical effects. Although not factory-related, recent studies on the visual impact of man-made objects in the landscape demonstrate that the kind of disturbances perceived by those living nearby are often associated with a disruption to the sense of place [13], [14]. However, it is worth noting that correlation between the proximity and degree of acceptance of an intervention does not always exist: there is evidence of an "inverse NIMBY syndrome" when the man-made object has some positive environmental implications [15].

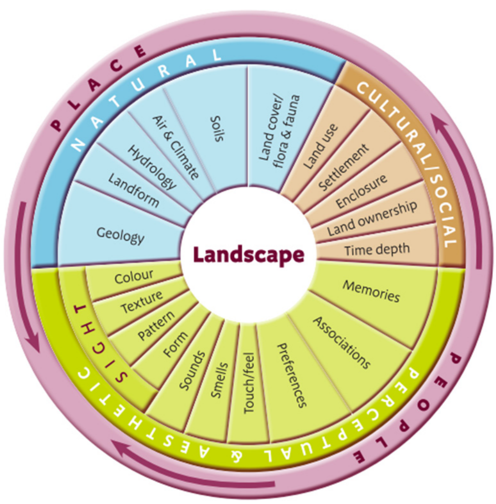

Figure 1: Landscape components [3].

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2.1 The agri-food industry

In the industrial context, the agri-food sector – which refers to the processing of agricultural, forestry and fishing products into edible food and drink for human beings or animals [16] – is specifically affected by the issue.

Firstly, because it often involves high energy and resource-consuming processes, as well as practices that compromise the quality of the ecosystem (e.g. the thermal pollution of rivers through wastewater) [17].

In addition, as there is a close relationship between the processing of edible goods and the quality of the environment from which they originate, the production site and location play an important role in company image [18]. This is particularly true for typical products in certain cultivated landscapes [19] and evidenced by the increasing number of wineries investing in sophisticated and sustainable production buildings [20]–[22].

Lastly, the vast majority of agri-food facilities are scattered throughout the country in or near rural areas, often within territories designated as high-quality landscapes. Therefore, they heavily interfere with the perceptual-aesthetic quality of such sensitive sites.

2.2 Impact of factories on the landscape: between theory and practice

Growing awareness of global environmental problems has raised the interest of academics, policymakers and practitioners in this issue [5], [23].

On the one hand, literature and regulations have pushed the manufacturing sector towards more sustainable behaviours. Governmental measures to lessen the environmental impact have been implemented, such as penalties for lack of compliance, tax benefits and economic incentives [5]. Gradually, some planning, morphological and landscape aspects have also been addressed [17], [24], [25], mainly through guidelines. An increasing number of studies prove that the perceptual-aesthetic harmonisation of facilities into the landscape is important: many articles refer to renewable energy source projects [24], [26]–[28], energy infrastructures [13], and rural buildings [6], [20], [24], whereas industrial assets are still given little consideration.

On the other hand, there is evidence that firms now recognise their own impacts more clearly [29] and are trying to mitigate the effects. The rise in energy costs in recent years has driven companies to pay great attention to energy efficiency as a competitive factor, along with resource efficiency and pollution prevention [23], [30]. Besides, stakeholders' and consumers' more acute sensitivity to ethical and environmental issues is progressively influencing the attitude of businesses, which have turned sustainability into a long-term element of competitiveness [5], [31], [32].

Although still limited, some exemplary cases highlight that more effort has been put into designing buildings that are sympathetic to their surroundings by combining the three landscape components together. Furthermore, as some authors suggest that the communication of sustainable behaviour is as important for business as the attitude itself, Corporate Social Responsibility has spread [32] and design quality, traditionally devoted to company headquarters, has gradually also been applied to manufacturing sites [33]. However, several examples have shown that using factory architecture as a communication tool means – if it is not effectively combined with environmentally-friendly practices – running the risk of "Disneyfying" the work space or engaging in trivial "greenwashing" [32].

Although some positive trends regarding both theory and practice, they still tend to focus mainly on the environmental impact of factories; while the social/cultural and perceptual-aesthetic aspects are often neglected or managed separately despite being closely interrelated.

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3 LANDSCAPE COMPATIBILITY OF FACTORIES

The research deals with the landscape compatibility of factories and attempts to combine its multiple connotations into a consistent framework.

The basic assumption is that a deep reflection on harmonisation between production sites and the landscape is necessary not only to protect the environment and the closest communities, but also to promote the competitiveness of companies which act in a sustainable/conscious way. Thus, the objective is to define a system to analyse and promote the landscape compatibility of industrial buildings, considering the environmental, perceptual-aesthetic and social/cultural dimensions together. The aim is to help companies to mitigate their impact on the landscape by providing them with a design support tool.

To do this, the method we came up with breaks the process down into three steps:

1. Identification of a comprehensive list of impacts generated on the landscape by industrial facilities, occurring at site, building and process levels, followed by the development of a set of indicators to measure individual impacts and their weighted effects as a basis to identify intervention priorities.
2. Construction of a best practices catalogue to obtain an inventory of general mitigation tactics.
3. Development of a design support tool by combining the set of indicators (step 1) with the collection of best practices (step 2). The tool will be tested on an Italian agri-food company by analysing the major weaknesses and issues and then developing some mitigation scenarios for different kinds of facilities within the site.

The first two phases were undertaken in parallel and informed each other, while the third has yet to begin. The paper, however, focuses on the best practices catalogue (step 2).

3.1 Method

The second step of the research involves the study of exemplary facilities that have succeeded in reducing their impact on the landscape, thus increasing their level of compatibility.

The aim of the case studies collection is twofold: in addition to providing a catalogue of practices – which are useful as references when designing/renovating an industrial facility – it also allows the inductive formulation of mitigation tactics which can be combined and applied to other projects.

To do this, remarkable case studies were analysed using a structured methodology. Given the novelty of the topic, the cases were found not only in academic publications but also taken from trade literature (corporate websites), design competitions and awards (e.g. Green Company Award Industria e Paesaggio; GBE Factory; Brand & Landscape Award) and guidelines. As the purpose was to obtain a broad and general overview of the actual scenario, only secondary sources were consulted.

In order to select the cases, a functional classification was adopted: since the research focuses on agri-food many food factories were selected. In addition, other kinds of facilities were studied for the relevance of some adopted practices and their replicability in the agri-food industry. In fact, the cases were selected based on the strategies applied to achieve at least one of the following purposes:

- reduce environmental impacts at site, building and process level;
- lessen perceptual-aesthetic disturbances at site and building level;
- implement good practices regarding workers and neighbours.

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Table 1: Extract from the collection of case studies.

Case study	Country	Intervention	Year
Food industry (Ateco C10)			
Melinda	IT	RD and E	2014
Bio Pastificio IRIS	IT	NC	2015
Almazara Olisur Olive Oil Factory	CL	NC	2009
Stabilimento Maina	IT	NC	2015
Grandi Salumifici Italiani	IT	RD	2013
Solare Manufaktur Peter Backwaren	DE	NC	2012
Pastificio Felicetti	IT	NC	2014
Amadori	IT	RD	2016
Beverage industry (Ateco C11)			
UC Davis Wine and Food Facility	CA	NC	2013
Cantina Pizzolato	IT	RD and E	2016
Cantina Antinori	IT	NC	2013
Macallan distillery	UK	NC	ongoing
Carlsberg	FR	NC	2014
Energy facilities			
Centrale di cogenerazione Mozart	IT	NC	2009
Amager Bakke	DK	NC	ongoing
C.O.V.A. - Centro oli Val D'Agri	IT	RD	2015
Warehouses (Ateco H52)			
Celle ipogee Melinda	IT	NC	2004
Pedrali	IT	NC	2016
C.O.CE.A.	IT	E	2015
Iron and steel industry (Ateco C24)			
Thyssen Krupp AG Industries	DE	RD	2000
Deacero GMM	MX	NC	2010
Mechanical industry (Ateco C27-C29)			
Drexel und Weiss	AT	RD	2005
Stabilimento Omes	IT	NC	2004
Various			
Technogym Village	IT	NC	2012
Vitsoe	UK	NC	2017
Salewa	IT	NC	2011

Among others, new constructions (NC), redevelopment (RD) and the expansion (E) of the beverage industry, wineries, warehouses, the mechanical industry and energy facilities were considered (Table 1).

3.1.1 Two progressive levels of analysis

The selected cases were examined using the system of credits developed in the first stage of the research, which established an assessment protocol based on the U.S. GBC LEED Rating System. Despite being usually applied to quantitative aspects, the multi-criteria approach of sustainability Rating Systems was adopted as it provides a framework within which impacts of different nature and they synergies can be managed. Since some authors suggest that the

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subjective perception of aesthetic characters largely depends on cultural codes [34], [35], less strict limit between quantitative and non-quantitative gauges have been surmised. Therefore, some semi-quantitative indicators of aesthetic-perceptual attributes were found and applied in parallel with the quantitative parameters typical of the environmental impact assessments. In particular, *LEED v4 for BD+C: Warehouses and Distribution Centers* was chosen and extended by adding a new evaluation area referred to perceptual-aesthetic aspects. Like all the LEED assessment areas, this new one includes a set of indicators to measure each impact and the rules to combine them in order to calculate the corresponding credits.

The credit scheme used as an observation lens consists of 51 credits: Integrated Process (1); Location and Transportation (7 credits); Sustainable site (6); Water efficiency (5); Energy and Atmosphere (7); Materials and resources (5); Indoor environmental quality (10); Innovation (2); Perceptual-aesthetic aspects (8);

Hence, the case studies analysis was performed in two subsequent increasingly in-depth steps: an initial "horizontal" investigation followed by a "vertical" examination.

The first analysis level (horizontal) consists of a quick glance at the case study in order to ascertain whether it fits the protocol scheme and whether it is worth expanding on. Next, the project work credits are identified and reported in a table. The table, where the thematic areas and corresponding credits are arranged on the x-axis and the case studies on the y-axis, is filled in according to a binary code (on/off). Cases that had less than 2 credits "on" have been removed. Fig. 2 shows an extract of the dynamic table: the credits have been incorporated into the thematic areas column, which presents the number of "on" credits out of the total number of credits per area.

The next stage is the second level of analysis (vertical), which expands on the previous one. Each case study is described over two pages where the data is organised into six sections (Fig. 3): the first sheet contains basic information and builds the "identikit" of the project; the second provides an in-depth description of the adopted good practices. The collection of all these data sheets constitutes the best practices catalogue.

In particular, Section 4 provides a short but comprehensive summary of the project, which can help readers to choose whether the case is worth reading according to their needs. In Section 5 the good practices are extensively described within their context, hence reciprocal

Food industry (Ateco C10)	Integrated process	Location and Transportation +	Sustainable site +	Water efficiency +	Energy and Atmosphere +	Materials and resources +	Indoor environmental quality +	Innovation +	Perceptual-aesthetic aspects -	Morphological Harmonisation	Colour and Material Harmonisation	Noise Pollution	Smell Pollution	Site Accessibility and Receptiveness	Work Space and Leisure Area Design	Consideration of Symbolic Character	Corporate Image	
1 Melinda	□	1/7	2/6	0	2/7	1/5	5/10	1/2	3/8	□	■	□	□	□	■	□	■	15/51
2 Bio Pastificio IRIS	□	0	3/6	2/5	3/7	2/5	1/10	1/2	3/8	□	□	□	□	■	■	□	■	15/51
3 Almazara Olisur Olive Oil Factory	□	0	0	0	2/7	1/5	2/10	0	3/8	■	■	□	□	□	□	■	□	8/51
4 Grandi Salumifici Italiani	□	0	0	0	1/7	0	0	0	1/8	□	□	□	□	□	□	□	■	2/51
5 Solare Manufaktur Peter Backwaren	■	1/7	0	0	2/7	2/5	1/10	0	1/8	□	□	□	□	□	□	□	■	8/51
6 Kerrygold	□	1/7	0	0	3/7	0	1/10	0	0	□	□	□	□	□	□	□	□	5/51

Figure 2: Horizontal analysis: a black box means the credit is "on".

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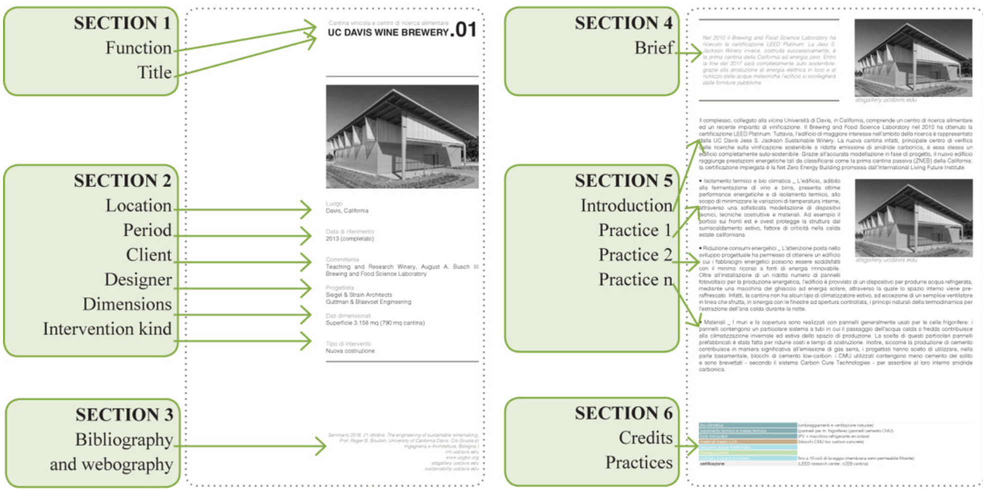

Figure 3: Vertical analysis.

Figure 4: From practices to tactics.

connections between practices are reported. Lastly, Section 6 summarises the practices using keywords and referring to credits, laying the foundations for the process of devising tactics. At the end of this procedure, the horizontal analysis is updated.

3.1.2 From practice to tactics

In parallel, the practices are collected in an Excel file where they are grouped by thematic area and linked to the corresponding credit. When two or more practices have a common denominator, a general tactic is inductively formulated (Fig. 4). For example, “green hill” to hide the height of the building and “land depression” to reduce the visibility of the complex are two practices which work with landform. Hence, “landform” is derived as a tactic. In addition, when the same practice recurs in at least two cases, it is considered common enough to become a general tactic.

3.2 Results and discussion

Thus far, 52 case studies have been “horizontally” analysed and 40 of them have also been “vertically” studied. A total of 234 practices were found in the collection and 112 general tactics were obtained.

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Table 2: Tactics and number of corresponding practices for the Perceptual-Aesthetic area.

Credit	Tactic	Practices
Morphological harmonisation	screen	7
	predominance of horizontal dimension	1
	landform	4
	underground building	2
	shape of local constructions	1
	shape of landscape features	2
	volume division into minors	1
	consistent layout	3
Colour and material harmonisation	colour from context	6
	texture from context	3
	green roof	2
	materials from context	2
	colour/graphic design	2
Noise pollution	screen with landform	1
	technological screen	2
Smell pollution	-	-
Site accessibility and receptiveness	multifunctionality	6
	social responsibility and territory promotion	1
	public park	1
Work space and leisure area design	workspace customisation	1
	workers participation in designing	1
	services and leisure spaces for workers	5
	workspace ergonomic	3
	environmental psychology for workspace	1
	non-hierarchical spaces	1
	space flexibility	1
Consideration of symbolic character	symbolical remind of local constructions	1
	preservation of iconic quality of the context	2
Corporate image	reference to the product	8
	consistency with company values	5
	certification	1
	industry 4.0 (openness)	3
	dynamic perception	3
	exhibition of the process outward	4
	awareness raising project	1

Although it is not complete, the catalogue of best practices can be already consulted by practitioners, professionals and companies who can find inspiration in some exemplary projects suited to their specific case. In fact, its division into sections makes it easy to find information for specific tactic/credit/thematic areas.

Furthermore, the first level of analysis facilitates both a direct comparison among case studies and statistical analysis by sector.

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Figure 5: From top left, clockwise: Thyssen Krupp (D); Cantina Antinori (I); Melinda (I); Amager Bakke (DK); Technogym (I); UCS Davis Winery (USA).

Lastly, the collection of case studies led to the recognition of several recurrent patterns which characterise some sectors or heterogeneous groups of case studies. The more significant ones are (Fig. 5):

1. Existing buildings, the visual impact of which is often mitigated by colour design (deconstruction, dematerialisation, camouflage, etc.)
2. Wineries, which emphasise the relationship between architecture and territorial identity, harmonising iconic design with the landscape where possible.
3. Food industries, which often use underground buildings as a strategy both to mitigate the visual impact and take advantage of ground thermal inertia.
4. Energy facilities that, with the association of leisure and production activities, are turned into multifunctional buildings and equipped with collective spaces.
5. Industries along highways, which experiment with dynamic perception leaving a rapid but memorable and effective impression of the building and creating an actual landmark in the landscape.
6. Zero emission factories, which often show(-off) technological devices as design elements.
7. Conclusions.

Although the research is in progress, the second stage described above provides some useful insights concerning the landscape compatibility of factories.

- The literature review points out that there is still a lack of integration between different aspects of the same topic: environmental impacts are often addressed both in research and practice, while social/cultural and perceptual-aesthetic disturbances are still rarely considered. However, this authors review of exemplary factories shows that several companies are heading in the right direction.
- Interestingly, the study highlighted that the more successful cases – in terms of prizes won or public acceptance – are those where the three areas of impact are addressed simultaneously. This is in line with Tandy's statement: "As the public becomes better informed, they are less likely to be satisfied with a mere cosmetic or "beautification' treatment" [17].

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- According to the evaluating framework developed in the first research stage, the second phase shows that the higher the number of "on" credits, the better landscape compatibility the factory has.
- In addition, a first list of tactics is made available and can guide practitioners or companies through the catalogue of case studies in search of exemplary corresponding practices to use as design references.

ACKNOWLEDGEMENT

This study was made possible and supported by Orogel Società Cooperativa Agricola, a leading company in the agri-food sector, based in Italy.

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HEALTH-ORIENTED EVALUATION OF THE SPATIAL DISTRIBUTION OF URBAN GREEN SPACE IN THE WUHAN INNER CITY AREA OF CHINA

YUPING DONG[1,2] & HELIN LIU[1,2]
[1]School of Architecture and Urban Planning, Huazhong University of Science and Technology, China
[2]Centre for Urban and Rural Planning Support Research, Huazhong University of Science and Technology, China

ABSTRACT

Research has proved that urban green space can be utilized to promote public health. While exploring the underlying mechanism, the main focus is always on the meso-scale characteristics of urban green space such as accessibility, availability, proximity, and its micro-scale attributes like area, quantity, constituent elements and environmental perception. Yet, its spatial distribution, as the macro-scale characteristics of urban green space, is also closely related to residents' health but has not well been explored. Regarding this, this paper takes the inner-city area of Wuhan as an example to evaluate the spatial distribution of the green space with Jiedao as the basic analysis unit. By buffer analysis and zonal analysis, the evaluation is conducted from five dimensions which are balance, equality, availability, accessibility and quality. The results show that, except in balance, the distribution of health-promotion green space is not satisfactory in the other four dimensions, especially in accessibility, quality and equality. The underlying causes could be attributed to three aspects of the current urban green space planning: (1) emphasis on ecology-oriented value and the application of "top-down" planning approach; (2) adoption of a single-dimension index system; (3) application of a static but not an adaptive framework. Therefore, from planning perspective, to shift the value-orientation and readjust the framework of urban green space planning will be one key solution to the identified problems.

Keywords: health-oriented, urban green space, evaluation, planning, Wuhan inner city area.

1 INTRODUCTION

Substantial studies have proved that urban green space can promote public health through both regulating ecosystem services (such as improving air quality, relieving heat island effect) and cultural ecosystem services (such as improving physical activity, reducing stress) [1]. Despite this fact, it is still common to see green space land being squeezed by other land uses during the urbanization processes. As a result, on the one hand it leads to unequal accessibility and availability of health-related benefits from urban green space [2]; on the other hand, it causes the planning and management of green space in urban area a challenge [3]. What's more, the prevalence of sedentary life style and high stressful living environment deteriorates residents' sub-health status [4], [5]. Therefore, it is significant to examine the spatial distribution of urban green space from health-promotion perspective so as to facilitate exploration of planning solutions to the identified problems.

However, on this topic most studies in China tend to focus on landscape appreciation and eco-value rather than equality and accessibility [6], [7]. Hu et al. [8] insisted that the existence of green space does not means it can be physically or socio-economically accessed by residents. Even if those dimensions are counted, the focus is on the supply of the resource itself but not its health effect to users [9], [10]. In other words, those studies are more likely to study availability rather than accessibility. That is, the principle is space-oriented rather than user-oriented. Moreover, from the health-outcome perspective, it can be identified that good availability does not mean that the green spaces can function well in terms of health-promotion. For example, Hystad et al. [11] find that birth outcomes have a positive and linear relation with residential greenness level when the NDVI (Normalized Differential Vegetation

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180041

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Index) value is or greater than 0.15. Similarly, Markevych et al. [12] get the results that low and moderate greenness level can lead to higher diastolic blood pressure for children, compared with high greenness level.

So, this paper aims to evaluate the spatial distribution of urban green space by integrating the health-promotion dimension. Firstly, it summarizes the indicators that can describe green space's potential to promote public health. Then we apply those indicators to evaluate the green space of Wuhan inner city from the perspectives of balance, equality, availability, accessibility and quality which are related to health-promotion. By referring to current distribution problems identified, the underlying causes are then discussed, and the correspondent solutions are proposed in the view of urban green space planning.

2 INDICATORS TO DESCRIBE HEALTH-ORIENTED CHARACTERISTICS OF URBAN GREEN SPACE

A series of research on the relationship between urban green space and health outcomes have adopted different indicators to measure users' exposure to green space, which can be combed into three categories, namely, accessibility, availability and self-feature. In detail, accessibility pays more attention to individual's actual acquirement and usage of urban green space with consideration of equality; availability focuses on the provision and distribution of but not residents' real engagement with the urban green space; self-feature concentrates on the nature of urban green space that could make difference in cultural ecosystem services.

The mostly adopted indicators to describe accessibility are as follows: NDVI and percentage of green space (PGS) within a buffer distance from a certain point (usually residents' home), distance from residents' home to a specific green space and residents' assessment/perception of accessibility to green space. For example, by measuring the PGS within the radius of 1 and 3 km around individual addresses respectively, Maas et al. [13] find that this indicator in both buffer distances has positive correlation with respondents' perceived health-benefits no matter what the urbanization degree is. By the same indicators, Maas et al. [14] find in another study that there is a significant relationship between accessibility and respondents' loneliness feeling. In other words, the greener the residents' living environment is the better accessibility and less loneliness they may have. They also report that increase of the PGS within a buffer of 1 km can reduce the feeling of lacking social support. Storgaard et al. [15] even prove that if the PGS within a 1 and 2.5 km buffer distance is lower than 5.4% and 8.6% respectively, residents would be more likely to have sedentary behavior compared with the situation that the PGS is greater than 20%.

From the perspective of availability, most studies use indicators as below: NDVI and PGS within a certain area, percentage of a specific green space (such as the proportion of park or public open space) in and assessed/perceived greenness of a certain area. For example, Almanza et al. [16] conclude that NDVI has a positive association with the rate of MVPA (moderate-to-vigorous physical activity). That is to say that high greenness level could promote MVPA. This finding aligns with a dose-response study derived from Grigsby-Toussaint et al. [17], in which greenness level (measured by NDVI) is proved to be the significant factor to influence preschool children's time for outdoor physical activity. Specifically, one unit increase of NDVI correspondingly can lead to an increase of about a 3-minute outdoor physical activity.

Of the many indicators to capture green space's self-feature, most are natural elements, types of available facilities, aesthetics/attractiveness, safety, general perception of quality and organized/programmed activities. For example, vegetation is considered as a vital natural element to improve environmental aesthetic, which contributes to attract more users and enhance their satisfaction [18]. Therefore, the perception of vegetation quality, such as its

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structure and diversity, could lead to difference in the usage of urban green space for outdoor physical activities [19]. What's more, according to the survey conducted by Schipperijn et al. [20], the natural elements like trees and water are the respondents' most favorite features which significantly increase their engagement in physical activities. More precisely, by a meta-analysis Barton and Pretty [21] find that improvement of self-esteem and mood increases by 0.29 and 0.19 respectively if there is water element in the green space.

The above review implies that: (1) most research focus on a relatively small-scale area, such as neighborhood, rather than the whole city to study health-related benefits by considering spatial equality. So those findings can only provide reference criteria for detailed planning of a certain site but not the overall layout of green space within a city for public health, an issue widely overlooked in planning practice; (2) health-oriented characteristics of urban green space are diverse, which means that a variety of indicators are needed to describe them. In addition, both quantitative and qualitative indicators are crucial for precise description of green space's potential to generate health benefits. Therefore, it is necessary to take different categories of indicators (including accessibility, availability and self-feature) into consideration while conducting health-oriented evaluation of the distribution of urban green space; (3) one characteristic of urban green space could generate more than one health-related benefit. For example, the PGS within a 1km buffer can contribute to general perceived health, loneliness feeling, social support, and physical activity level etc.

3 METHODOLOGY

3.1 Study area

Wuhan is the capital city of Hubei Province, located in the middle of China and the middle reaches of the Yangtze River. As one of China's megalopolises, in 2016 its urbanization rate is 79.77% and its GDP per capita is 111,469 Yuan. Wuhan covers 8,569.15 km^2 and consists of 13 districts (a district is a kind of administrative division level in China's cities. Each district in general consists of several Jiedaos and Jiedao is the lowest administrative level in cities in China). This research will focus on the inner-city area which consists of 7 districts (Jiang'an, Jianghan, Qiaokou, Hanyang, Wuchang, Qingshan and Hongshan) including 96 Jiedaos (including East Lake High-Tech Development Zone, East Lake Ecotourism Scenic Zone and Wuhan Chemical Industry Park) with a total area of 955.15 km^2 (Fig. 1).

In Wuhan, it is reported that residents' engagement in physical activity is of low frequency, usually less than 3 days a week [22]. In 2015, only about 480.2 thousand people take regular physical activity in Wuhan [23], which means that around 95% of the residents live a sedentary lifestyle. What's more, the space suitable for sport is insufficient as the sport field area is 1.43 m^2 per capita [24], lower than 1.57, the average level in China [25].

3.2 Study design

In this study, urban green space refers to all kinds of green land use within the boundary of Wuhan inner city. In addition, water (lake and river, etc.) is also treated as urban green space by considering two points: first, as a natural element, it functions like green space and can exaggerate or even directly generate health-related benefits; second, of the inner city area approximately one fifth is covered by water (The area of water body is extracted from remote sensing image). Considering data availability, we take Jiedao as the study unit. The vector Jiedao map with geo-locations and population in 2014 is offered by Wuhan Statistics Bureau.

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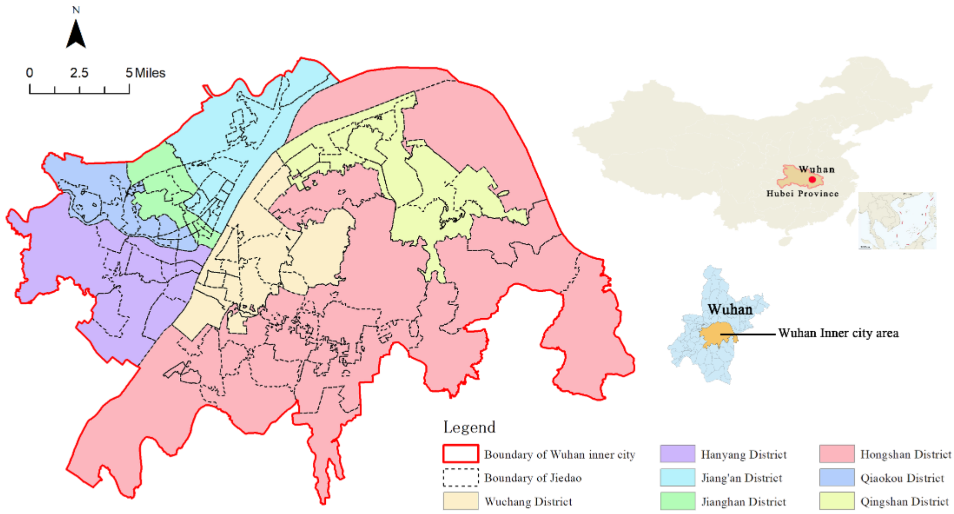

Figure 1: The location and the Jiedaos of Wuhan Inner city area

Series of studies have proved that characteristics of the spatial distribution of urban green space, like the distance (to/from a certain site), NDVI, PGS, etc., have a significant influence upon the level of outdoor physical activity. And epidemiological findings have revealed that regular physical activity could prevent chronic diseases and premature death [26]. Hence, for public health purpose it is meaningful to focus on the spatial distribution of urban green space, which may help to alleviate the threat from the non-communicable diseases that have been reported as the major risk to public health in Wuhan [22].

Firstly, we use concentration index and Gini Coefficient with the goal to identify the spatial distribution characteristics from a macro perspective. Then we evaluate the availability, accessibility and quality of urban green space by taking Jiedao as the analysis unit. Indicators adopted to describe those three aspects are NDVI, the percentage of urban green space within 1 km buffer distance and the ratio of arbor to shrub proposed by Zhu and Wu [27] and Zhang et al. [28], respectively.

3.3 Explanation of indicators

3.3.1 Concentration index

Concentration index is usually applied to measure the spatial concentration degree of certain resource. The equation is presented below and detailed explanation of it can be found in Rui et al. [29] and Zhu et al. [30].

$$C = \left(\sqrt{\sum_{i=1}^{n} \left({H_i}/{S} \right)^2} \Big/ \sqrt{\sum_{i=1}^{n} \left({1}/{n} \right)^2} \right) - 1, \tag{1}$$

where H_i represents the area of green space (including water body) within Jiedao i; S represents the total area of green space (including water body) within Wuhan inner city area; and n represents the total number of Jiedao within Wuhan inner city area (it is 96 in our study).

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3.3.2 Gini Coefficient

Gini Coefficient is an index proposed by Gini, the Italian economist, in 1922 to quantitatively measure the income gap among different groups. Nowadays, it has evolved into many revised forms in different fields. In this paper we adopt what Wu [31] has proposed. When the area density (It refers to the percentage of green space within Jiedao unit) of green space within every Jiedao unit is calculated and ranked in an ascending order, then the Gini Coefficient G can be calculated by the eqns (2)–(4):

$$\mathrm{G} = \sum_{i=1}^{n-1}(F_i * R_{i+1} - F_{i+1} * R_i), \quad (2)$$

where

$$F_i = \sum_{k=1}^{i}({}^{P_k}/_{P}), \quad (3)$$

$$R_i = \sum_{k=1}^{i}({}^{H_k}/_{S}), \quad (4)$$

where P_k represents the number of residents within Jiedao *k*; *P* represents the total number of residents within Wuhan inner city area; H_k represents the area of green space (including water body) within Jiedao *k*; *S* represents the total area of green space (including water body) within Wuhan inner city area; *n* represents the total number of Jiedao within Wuhan inner city area (it is 96 in our study).

3.3.3 NDVI

NDVI is usually applied to measure the greenness of residential environment, which has a strong association with perception of greenness, urban green space usage, physical activity, mental health outcome, etc. The value of NDVI is derived from near-infrared (NIR) bands and visible red (RED) bands of remote sensing image and it ranges from -1(usually regarded as water) to +1 (usually regarded as lush vegetation coverage). In this study, we obtain the NDVI values with a resolution of 30 m × 30 m based on the sensing map from Landsat8 (OLI_TIRS) in July 23th 2016. The mean NDVI value for each Jiedao is calculated by zonal analysis supported by spatial analyst tools in Arcgis 10.2.

3.3.4 Percentage of green space (PGS)

The PGS within a certain buffer distance is usually applied to measure the accessibility of urban green space [32]. In this study, the buffer distance around the centroid of Jiedao is defined to be 1 km (straight-line) which is commonly used in research on the health outcomes of urban green space [14]. The centroid of each Jiedao is treated as the clustering point of population and its coordinate is the default XYs in Arcgis 10.2.

3.3.5 The ratio of arbor to shrub

High accessibility does not mean high usage if urban green space is of poor quality in aesthetics and design. Therefore, it is significant to consider urban green space's quality for health-oriented evaluation of its distribution. For this paper we use the ratio of arbor to shrub proposed by Zhang et al. [28] as the indicator. The vegetation types (namely, grass, bush and tree) is classified based on the suggested NDVI value intervals [33] and the local context in Wuhan. Then for each Jiedao, the area of trees and for bushes within the one-kilometer buffer are extracted respectively by zonal analysis with Arcgis 10.2, which provide the required data for the calculation of the ratio of arbor to shrub.

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4 RESULTS OF THE EVALUATION AND THE UNDERLYING CAUSES

4.1 Results of the evaluation

From eqn (1), it is calculated that the concentration index of the current urban green spaces approximates to 0.86. If the green spaces are evenly distributed in the 96 Jiedaos, the corresponding index value is 0; and if all the green spaces are in the largest Jiedao, then we have the maximum value for the concentration index which is 4.6. So, regarding the value of 0.86, we can conclude that without considering demographic elements the spatial distribution of the green space in Wuhan inner city are is relatively even.

Yet, if we count in the people that the green space has to serve in each Jiedao, then we will see that the spatial distribution of green space in Wuhan inner city area is seriously unfair as the Gini Coefficient is around 0.695, much higher than 0.5, a value meaning seriously unfair according to general criteria [31].

Based on the NDVI map (Fig. 2), we can generate the detailed NDVI distribution map at Jiedao-level (Fig. 3) by zonal analysis. It can be seen that, although the greenness level is high in the whole inner-city area, the NDVI values are relatively low for the Jiedaos and most of them are between 0.15 and 0.45, especially in the interval of [0.25, 0.35]. What's more, Jiedaos next to the suburban areas have a relatively higher greenness level while the ones in the very central area have a lower level, even with some Jiedaos having a value lower than 0.15. According to findings by Hystad et al. [11], it means that the current greens in these Jiedaos cannot function well to generate significant benefits for pregnancy and birth.

As explained, water to some extent can function like green space to attract people to take physical activities around. But people cannot wander in water like what they can do on grassland and in woods. Regarding this difference, the accessibility of urban green space is calculated by PGS in two scenarios: one with water included and the other with water excluded. The results are depicted by Figs 4 and 5, respectively. It is evident that, in terms of health-promotion, most Jiedaos have poor accessibility to urban green space, especially those Jiedaos in the central part. Even if water is counted in, we can still see that Jiedaos in Jianghan, Qiaokou and Hanyang districts have very lower greenness accessibility.

After zonal analysis, the ratios of arbor to shrub for all the Jiedaos are shown in Fig. 6. According to Zhang et al. [28], when the ratio of arbor to shrub approximates 1:1.5 (namely, 0.667), to user's feeling the aesthetic quality of urban green space can be better. So, the results (Fig. 6) imply that the aesthetic quality in most Jiedaos still have much space to improve. And if we compare it with Fig. 5, we can see that many Jiedaos have a low quality of urban green space even though they enjoy relatively high accessibility.

According to the results above, we can see that the spatial distribution of urban green space in the inner-city area of Wuhan is well balanced among different Jiedaos in a general sense. Yet, if we consider the residents that each Jiedao has to serve, then it is evident that most Jiedaos, especially those in the central part of the inner-city area have a relatively low availability and accessibility, even if water is treated as green space. In addition, the aesthetic quality of the green space is also not satisfactory in most of the Jiedaos, particularly those once specializing in traditional heavy industries and old transport complex.

4.2 The underlying causes from planning perspective

The identified problems above may result from many causes, such as the bequeathed built-up environment based upon overemphasis on work rather than leisure in urban life or overlook of the quality of public open space in cities in the second half of the 20th century

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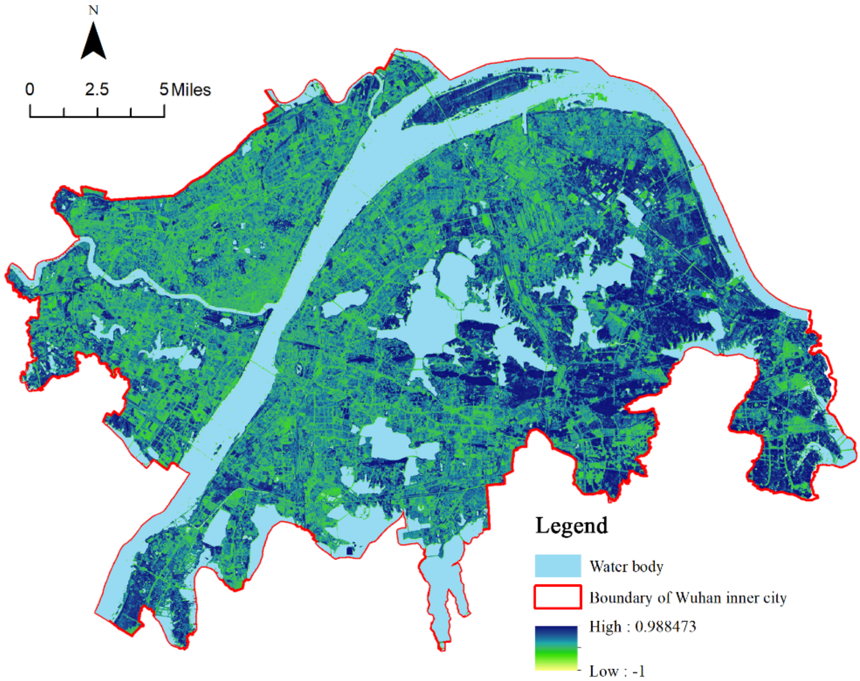

Figure 2: The NDVI of Wuhan inner city area.

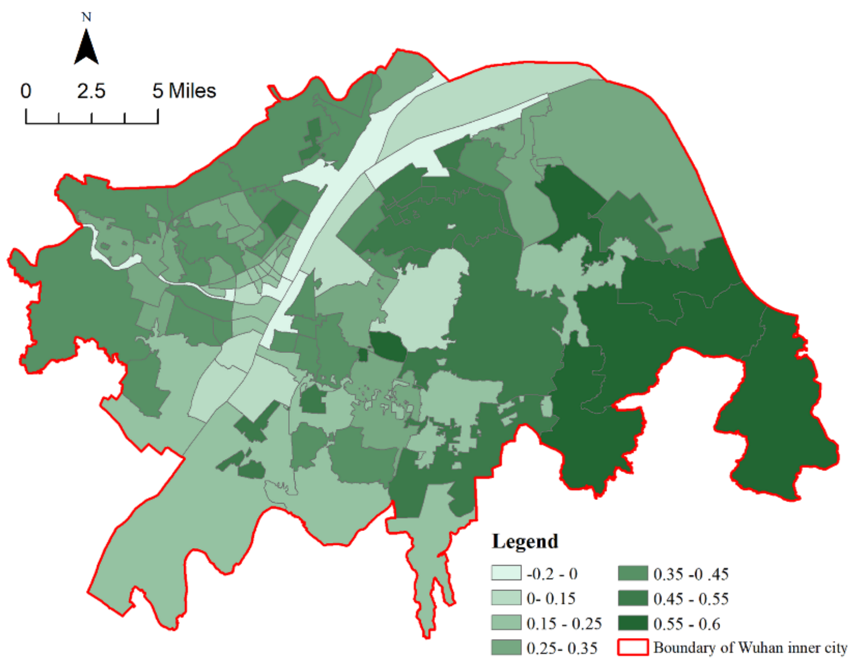

Figure 3: The NDVI distribution at Jiedao-level.

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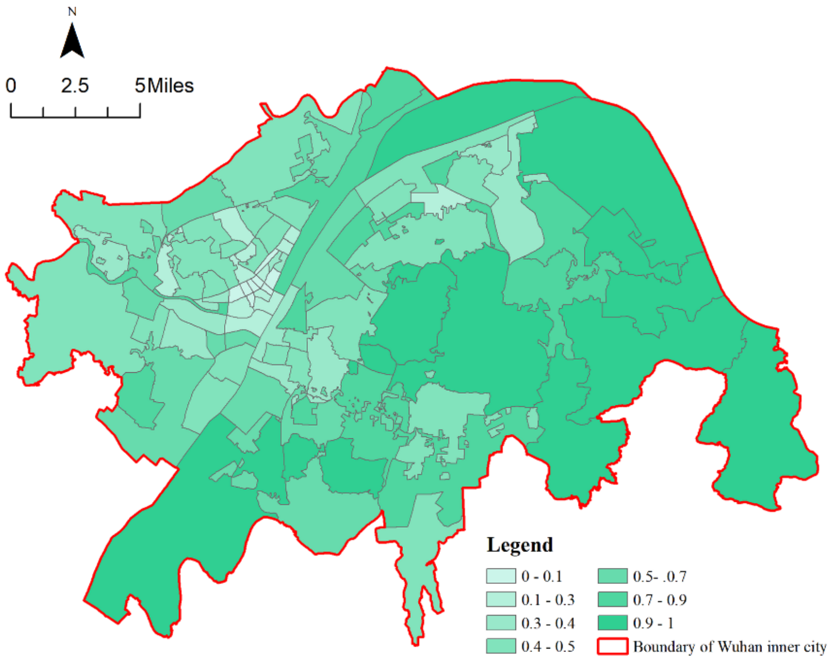

Figure 4: The percentage of urban green space within a buffer distance of 1 km (with water).

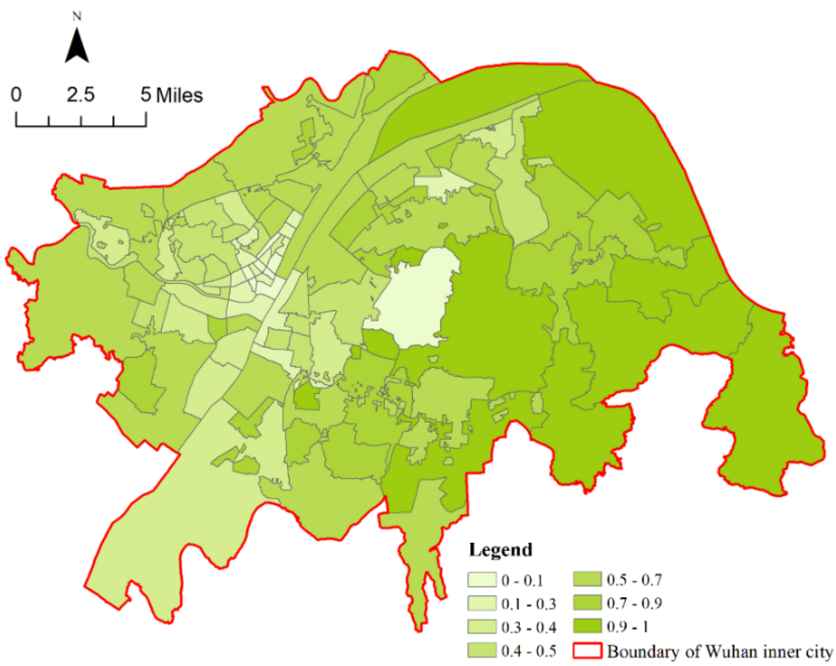

Figure 5: The percentage of urban green space within a buffer distance of 1 km (without water).

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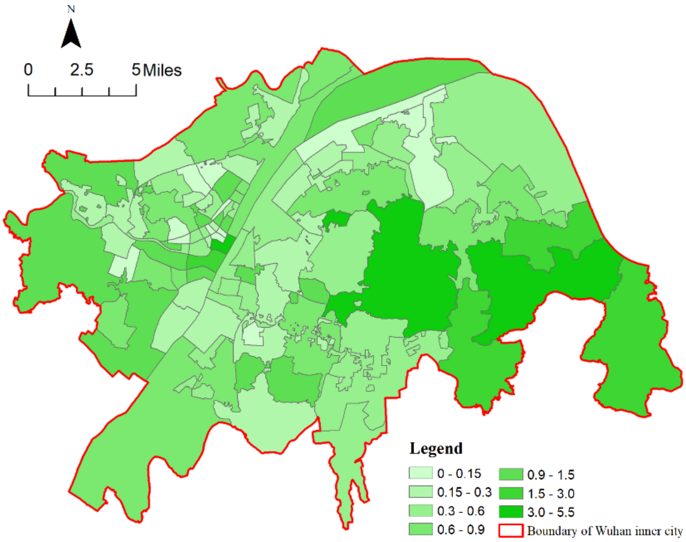

Figure 6: The ratio of arbor to shrub within a buffer distance of 1 km.

in China. Yet, from the perspective of urban green space planning, we may attribute these issues to three dimensions. The first one is about the planning framework. In China, urban green space planning has been for such a long time regarded as a theme planning guided by the "top-down" approach. It means that urban green space planning is subordinate to master planning and should absolutely conform to it. So, what the central business urban green space planning has to deal with is to give more details to the pre-proposed "green space plan" by the related superordinate plans. Hence, as an echo to the idea of "garden city", "forest city", and "sponge city", to embody the ecological value rather than health benefits of urban green space is the key in its planning.

The second dimension, as a result of the first dimension, pertains to the indicators being applied in urban green space planning. As ecological value is the key, the amount of greenness is always the key in planning practice. So, there are almost no health-oriented indicators in the index system of urban green space planning and as a result residents' real demand of and access to urban green space has seldom been seriously considered. This further leads to the fact that availability rather than accessibility is emphasized in the index system even though accessibility is more or at least equally crucial for health-promotion [34]. So, it is not surprising to see that most Jiedaos have poor accessibility to and quality of urban green space.

The last one is related to the process and content of urban green space planning. Currently, urban green space planning is not treated as an incremental process but as a one-off work to draw a static blueprint. The central task is to define urban green space's overall function, to map its boundaries, and to detail the allocation of different types of green space (such as buffer green space and public green space). Inevitably, the dynamic characteristics of the green space and its interactions with urban development cannot be captured in the plans [35]. As a result, issues, such as management and improvement of the urban green space, its effects on the involved residents and local area, are always ignored, which might explain why green space with low quality and accessibility level tend to concentrate in some old areas in the inner city of Wuhan.

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5 CONCLUSION

Through five indicators, this paper evaluates the spatial distribution of urban green space in Wuhan inner city area by taking Jiedao as the analysis unit. The results reveal that from the perspective of health-promotion, its spatial distribution is relatively even in a general sense. Yet, if we consider residents' real demand of and accessibility to green spaces, we can see that most Jiedaos, especially those featured by old communities/factories have very low performance in both availability and accessibility. In addition, the quality of urban green space is also not satisfactory in many Jiedaos around the center of the inner-city area. The underlying causes to these issues from planning perspective, as has been explained, can be summarized into three key dimensions: urban green space's subordinate role in the ecology-orientation planning system; overlook or even ignorance of the health-promotion indicators in the planning index system; and a static view rather than an incremental view of the planning process.

Therefore, for health-promotion purpose, it is vital to shift from the ecology-centered value-orientation to a new one with both ecological and health values equally pursued. This will be the foundation for the establishment and application of the health-oriented indicators to be integrated into the planning index system; This shift also entails more attention to be paid to the users' socio-economic status and daily behavior. So, both the "top-down" and "bottom-up" approaches are needed so as to encourage public participation and promote the integrity of different levels of plans. Thus, the changing demands from residents can be identified in time and health-promotion can be equally emphasized in each planning step so as to keep urban green space function effectively for public health.

For a better development of this research, three points pertaining to the method need further effort. First, as the maps of NDVI and PGS are produced based upon the remote sensing image with a resolution of 30 m × 30 m, inevitably green space smaller than 900 m^2 cannot be captured when calculating the relevant indicators. So, in Jiedaos, especially in the old ones where high density of construction and fragmented greens are more common to see, the calculated values might be lower than the real value. Whether it is true or not may need further on-site investigation or application of a higher resolution remote sensing map. Second, to evaluate availability and accessibility, the residence locations are supposed to be the centroids of the Jiedaos, which can cause inaccuracy of the evaluation. So, in order solve this problem, it is crucial to get the full map of all the residential communities in the study area which might be obtained by mining the mobile signaling data in Wuhan. Third, for each of the three dimensions (availability, accessibility and self-feature), only one indicator is applied. This in deed cannot reflect the full landscape of each dimension. So, what we need to do the next step is to propose and apply a more reasonable and comprehensive but succinct indicator set to represent each dimension in the evaluation.

ACKNOWLEDGEMENTS

This work is supported by the Science and Technology Department of Hubei Province under Grant (number 2017ADC073); China Thousands Talents Program under Grant (number D1218006).

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USERS' PERCEPTION AND EVALUATION OF CAMPUS ECO-OPEN SPACES AT THE UNIVERSITY OF LAGOS, AKOKA CAMPUS, NIGERIA

NNEZI UDUMA-OLUGU, OLAWALE IBRAHIM OLASUPO & JOHN ADEKUNLE ADESINA
Department of Architecture, University of Lagos, Nigeria

ABSTRACT
The design and conception of a university campus is usually done in a manner to create an attractive, conducive atmosphere which is serene as well as beautiful to encourage a right environment for study. University of Lagos prides itself as the University First Choice and the nation's pride in Nigeria. The university's unique location besides a lagoon and in an urban setting, gives it the opportunity to exploit the benefits of water tourism and other forms of nature in form of recreation within the eco-open spaces on campus. The aim of the study was to examine people's perception of the green infrastructure provided, the serenity of the existing eco-open spaces which students always visit due to their biophilic aspects, subsequently evaluate the facilities provided and how they are received by the users. A survey of eighty (80) copies of photo-questionnaires distributed to respondents, which consisted of students, visitors and staff who met at the various venues. Out of these, 77 were returned correctly filled and used for analysis. Conclusions were reached and recommendations made, in line with the results of the study.
Keywords: campus eco-open spaces, green infrastructure, landscape perception, landscape urbanism, recreation.

1 INTRODUCTION

In studying people's perception of the open spaces in various parts of the University of Lagos, it is necessary to define open space – open space is defined in the Town and Country Planning Act 1990 as land laid out as a public garden, or used for the purposes of public recreation, or land which is a disused burial ground. However, in this study, open space should be taken to mean all open space of public value, including not just land, but also areas of water such as rivers, canals, lakes and reservoirs which offer important opportunities for sport and recreation and can also act as a visual amenity.

The following typology illustrates the broad range of open spaces that may be of public value:

- Parks and gardens – including urban parks, country parks and formal gardens;
- Natural and semi-natural urban greenspaces – including woodlands, urban forestry, scrub, grasslands;
- Green corridors – including river and canal banks, cycleway, and rights of way;
- Outdoor sports facilities (with natural or artificial surfaces and either publicly or privately owned);
- Amenity greenspace (most commonly, but not exclusively in housing areas) – including informal recreation spaces, greenspaces in and around housing, domestic gardens and village greens;
- Provision for children and teenagers – including play areas, skateboard parks, outdoor basketball hoops, and other more informal area (e.g. "hanging out" areas, teenage shelters);
- Allotments, community gardens, and city (urban) farms;

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180051

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- Cemeteries and churchyards;
- Accessible countryside in urban fringe areas; and
- Civic spaces, including civic and market squares, and other hard surfaced areas designed for pedestrians.

An open space network should encourage more active lifestyles by offering a variety of safe and attractive spaces that are well distributed throughout a neighbourhood and are accessible and cater to the sporting and recreational needs of the community [1]. Preferably public open space should attempt to cater for multiple users.

Biophilic open spaces as it relates to the university, are elements and qualities of the physical environment that connect people to the physical, psychological, and cognitive benefits derived from direct, indirect or symbolic experiences with nature. These natural attributes are preferable in part because they literally bring buildings to life physically through the use of design strategies and materials, and symbolically through an understanding of deeply rooted affiliations, associations and meanings. Biophilic open spaces design attributes include: dynamic natural light, natural ventilation, access to open and/or moving water, frequent opportunities for spontaneous interaction with nature, sensory connections to nature, complexity and order, mystery, prospect and refuge, fundamental natural forms, and local natural materials [2], [3].

Immersion in natural environments is even more beneficial. Physically, patients recover faster when exposed to images and elements of the natural environment both before and after surgery [4]. Researchers have consistently found that people with access to nearby natural settings are healthier than other individuals [5]. Encouraging and enabling connections is highly beneficial both emotionally and physically.

Perhaps more importantly, this detachment between humanity and our natural environment has led to apathy towards the effects of our actions on the biosphere which, creates greater environmental problems by isolating the community from our natural surroundings, we place our mental and physical health at risk [4]. Nature is beneficial to all regardless of age, race, gender, or ethnicity. Contact with nature has been found to promote recovery from stress and disorder. Certain plants and habitats have been associated with stress-relieving, curative effects, calming, healing effects on the sick, and disposure of patients to therapeutic gardens can produce symptoms relieving [4], [6]. Much of the foregoing research discussed the effect of nature on recovering patients. This study concentrates on the effect of nature and eco-open spaces on its users within a university setting. The aim of the study is therefore to:

1. Study the open spaces on the campus.
2. Determine the provisions that are available for users.
3. Investigate the perceptions of the users of the eco-open spaces provided on the campus.

2 LITERATURE REVIEW

2.1 Eco-open spaces perceptions

There are five essential principles of biophilia which can be applied to architecture either for the purpose of guiding the development of the design as well as evaluating its merits: affiliation and affinity, wellness, bio centric ethics, prospect, and refuge and homeostasis [2], [4]. These principles relate to the elements of building design, some more strongly than others. The biophilic principles are all strongly connected, just as there is truly no clear line

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between each of the building elements, each affects and interacts with the others, working together to form a cohesive whole.

2.1.1 Affinity and affiliation

There are four basic levels of affiliation for developing biophilic affinity. These four levels of affiliation are contact, association, views and proxy. While each level of affiliation can develop biophilic affinity, the more personal and immediate the affiliation, the stronger the psychological and emotional connections will be. Affinity consists primarily of emotional connections which cause humans to attach value to some item. Contact is the most immediate level of affiliation which occurs when we associate with elements to the point where they enter our personal space, including physical contact. Such affiliation is more powerful due to the intensity of sensation caused by the physical closeness of item which involves senses of touch and smell.

2.1.2 Wellness

People who have had more exposure to the environment are healthier in a broad range of ways. They are less likely to have mental illnesses, develop attention deficit disorders, suffer from excess stress, which causes additional health issues and are less likely to be obese or overweight, which causes even more health problems.

2.1.3 Bio centric ethics

Ethics are the theoretical or philosophical concepts behind morality. Environmental ethics begins essentially with the issue of instrumental value versus intrinsic value done to the environment. Or, on the other hand, is there an intrinsic value to the natural environment outside of what it means to us as humans?

2.1.4 Prospect and refuge

Human beings naturally seek high ground and shelter for protection and in order to get a better view of our surroundings. The comfort and relaxation we feel looking out over a vista is an aspect of a human survival trait, not simply a matter of aesthetics. The concept of prospect and refuge is the most directly applicable biophilic principle in architectural terms.

2.1.5 Homeostasis

Homeostasis is defined as ‘a relatively stable state of equilibrium or a tendency toward such a state between the different but interdependent elements or groups of elements of an organism, population, or group’. The natural world exists naturally in a homeostatic, largely self-corrective state. Removing elements from that natural cycle or ignoring the cycle entirely can throw the entire system out of balance and makes the return to homeostasis much harder.

2.2 Therapeutic effect of natural surroundings

A large body of research has confirmed the hypothesis that, contact with nature can lead to increased mental health and psychological well-being [2], [4], [7]. Many studies have found that contact with actual rather than representational nature has the most consistent and powerful therapeutic effects. To determine the benefits of experience with nature, it is essential to determine the types of contact we have with the natural environment. The contact is not limited to only a natural environment or landscape but could include the simple notion of nature. According to Kellert [2], there are three types of contact we can have with nature: direct, indirect and symbolic.

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Direct contact involves immediate experience with natural processes such as hiking through a forest, swimming in a stream or mountain climbing. Direct contact usually involves a person immediately within a natural environment.

Indirect contact involves some kind of human intervention or control such as mowing a lawn, viewing an aquarium or gardening.

Symbolic contact does not require any physical contact with natural processes or organic life forms. It involves a symbolic or metaphoric encounter such as depictions of landscapes in art or photographs or the use of organic patterns and forms in either decoration or architecture.

According to environmental psychologists contact with the natural environment can have a psychologically restorative effect on people. Restorative environments whether they be in the context of nature or the built environment, incorporate elements that function therapeutically by reducing cognitive fatigue and alleviating stress. These environments provide opportunities for rest, recovery, contemplation, and isolation [4]. The positive effects from contact with nature or natural views have proven to be greatest when people are experiencing high levels of stress or are confined to situations like hospitals, prisons and work environments.

In this case frequent direct, indirect or symbolic contact with nature continue to have a positive physical and psychological effect on human well-being. Kellert [2], identifies four benefits of contact with nature in built environment; Nature tends to correlate with physical activity which obviously promotes health. Nature activities often imply socialization in form of walking in group, sitting in a park with friends, building social network. Nature offers temporary escape from every day routine and demands. To what extent interaction with nature can have an appreciable impact on the mind. These benefits of contact with nature can be explained further in three ways [5], The air may be healthier in that it contains less air pollutants and more humidity. Plants may emit fragrance that humans find pleasant or react to in various ways. Visual experience of plants makes difference in that nature appears to have qualities useful for stress relief, mental restoration, and improve mood simply by consciously or unconsciously pleasing to the eye. Humankind does not merely have a preference for natural landscapes, they are also important to our physical and mental health. Numerous studies have shown that regular exposure to natural elements is highly beneficial to mental health, particularly stress reduction [8].

2.3 Biophilic design approach in the planning and designing of the open spaces

The adoption of biophilic design approach and framework in the planning process will lead to mental benefit, physical benefit and social benefit for the users; mental benefit in terms of stress and violence reduction, improved concentration. Physical benefit in the areas of enhancing health, rapid healing, and improved campus environmental condition. Social benefit which is crime reduction, student productivity, economic stimulation, better academic studies and greener open spaces. It is necessary to consider users' perception of the open spaces within the campus as it relates to the aforementioned human psychological, emotional and the physical factors that determine how the spaces are used.

The various attributes of a biophilic open space design cannot be over emphasized as they are key to the connectivity and usability of the various open spaces and the presence of nature improves health and well-being of its users. It reduces heat, improves air quality, reduces noise, stimulates fauna and flora, cleanses water runoff for the environment. Both the value and aesthetics of the open spaces improves the green rating of the environment. A biophilic eco-open space protects the users and the facilities from direct exposure to harsh elements.

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2.4 The people's psychological perception of the campus open spaces

The human perceptions of the open spaces within the campus as it relates to the human psychological, emotional and the physical factors that must be given considerations. The foremost importance of an eco-open space having the biophilic attributes is therapy. Petelot [9], argued that the interactions with green spaces are essential for mental wellbeing "our green spaces are essential for mental wellbeing, our garden allows us to work the earth, to watch things grow" people often times scratch the soil, breathe in the scent of plants and flowers let off steam and meet other people.

The physical form of a university's open spaces provides safety, security, accessibility, social interaction and campus entertainment. Based on the social lifestyle of the students, hyper-density leads to a decline in the social relations and make people avoid contact when the open space is hyper-dense, but the university's context shows the opposite meaning the open spaces never experience hyper-density which could affect the student psyche. Nevertheless, the eco-open spaces provide psychological comfort, healthy environment, recreation and ecological naturalness. Steptoe and Feldman [10] assure that hyper-density environment leads to poor health.

3 METHODOLOGY

The first stage focused on identifying the eco-open spaces in the Campus. Secondary data from topographical maps, 2017 satellite images, previous soil and hydrological studies and field work were used to document existing vegetation and open space network of the University. A key component of the technical analysis was the on-site quality assessment, which considered site condition, provision of facilities and level of maintenance. Sites were assessed using a methodology that scored them on a one to four (poor, fair, good or excellent) basis. Generic criteria, (such as safety, accessibility and how welcoming the site is, applied to all sites and specific criteria such as biodiversity, horticultural excellence and play value) were used for particular sites.

The final stage involved the data collection through a survey of one of the sites. This stage included the use of structured interviews of students and various users' opinion to document perceptions of the university's eco-open spaces. Data was collected through purposeful sampling; a primary survey of eighty (80) questionnaires distributed to respondents, which consisted of visitors, staff and students of the University of Lagos. Out of the eighty copies of questionnaire distributed only seventy-seven (77) was successfully filled and returned to the researchers. Based on this, the presentation and analysis were done; using frequency distribution tables to presents the respondents' demographic data. These were analyzed using Statistical Package for Social Sciences (IBM Statistics SPSS 20.0).

4 RESULTS

4.1 presentation of respondents' demographic characteristics

This section presents the respondents' demographic data using frequency distribution tables.

Table 1 reveals that 52 or 67.5% respondents were between the age 16–30 years of age, 24 or 31.2% respondents are within the age bracket of 31–45 years, while 1 or 1.3% respondents are within the age brackets of 46–60 years. This table's results are not surprising since it shows that mostly young people that are between 16–30 years of age responded to the questionnaire – this is the expected age bracket of most students in the university.

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Table 1: Percentage distribution of respondents' by age. *(Source: Field Survey, 2016.)*

		Frequency	Percent	Valid percent	Cumulative percent
Valid	16–30	52	67.5	67.5	67.5
	31–45	24	31.2	31.2	98.7
	46–60	1	1.3	1.3	100.0
	Total	77	100.0	100.0	

Table 2: Percentage distribution of respondents' by gender. *(Source: Field Survey, 2016.)*

		Frequency	Percent	Valid percent	Cumulative percent
Valid	Male	27	35.1	35.1	35.1
	Female	50	64.9	64.9	100.0
	Total	77	100.0	100.0	

Table 3: Percentage distribution of respondents by highest educational qualification. *(Source: Field Survey, 2016.)*

		Frequency	Percent	Valid percent	Cumulative percent
Valid	Primary school	7	9.1	9.1	9.1
	Secondary school	28	36.4	36.4	45.5
	Technical school/ polytechnic	4	5.2	5.2	50.6
	BSC/BA	23	29.9	29.9	80.5
	MSc/Ph.D	15	19.5	19.5	100.0
	Total	77	100.0	100.0	

Table 2 shows the distribution of the respondents by sex, 35.1% of the respondents were male, while the remaining 64.9% of them were female. This indicates that the majority of respondents that attended to the questionnaire were female.

Table 3 indicates that 7 or 9.1% respondents were primary school holders, while 28 or 36.4% respondents were secondary school holders, 4 or 5.2% respondents have technical school or polytechnic certificates, 23 or 29.9% respondents and 15 or 19.5% respondents were MSc/PhD holders. This table shows that majority of respondents were mostly educated which is to be expected within a university environment.

Table 4 shows that 24.7% respondents are visitors to the university, 49.4% respondents are undergraduate students of the university of Lagos, 20.8% respondents are post graduate students of the university while 5.2% respondents are staff of the school. This table shows that majority of respondents are undergraduate students.

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Table 4: How would you describe yourself? *(Source: Field Survey, 2016.)*

		Frequency	Percent	Valid percent	Cumulative percent
Valid	Visitor	19	24.7	24.7	24.7
	Undergraduate students	38	49.4	49.4	74.0
	Post graduate students	16	20.8	20.8	94.8
	Staff	4	5.2	5.2	100.0
	Total	77	100.0	100.0	

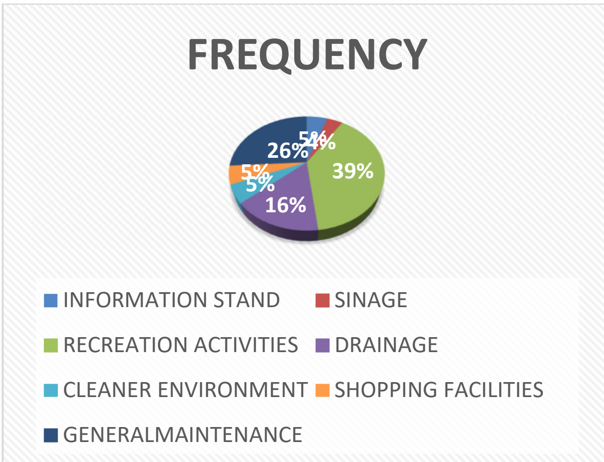

Figure 1: What key facilities are missing in the open spaces that you will like provided/improved? *(Source: Field Survey, 2016.)*

4.2 Respondents perceptions

Fig. 1 shows that 5.2% respondents said they will like the university to provide or improve on information stands, 3.9% respondents said signage, 39% respondents said recreational activities, 15.6% respondents said drainage, 5.2% respondents said cleaner environment 5.2% respondents said shopping facilities, 26% respondents said general maintenance This figure shows that majority of respondents wants more recreational facilities to be created by the university.

Table 5 shows that 13% respondents said they consider students hostel of the university as the best landscape, 14.3% respondents chose the staff housing provided by the university, 22.1% respondents chose the academic areas of the university, 15.6% respondents chose the recreational areas of the university, 19.5% respondents chose the circulations zones of the university (Roads, Pathways, car/bus parks) and 10.4% respondents chose the landmarks (water tank, senate building and entrance gates). This table shows that majority of respondents considers the academic areas of the university as the best landscape of the university, while the recreational areas only ranked third best.

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Table 5: Where would you consider the best landscape open space in the UNILAG campus? *(Source: Field Survey, 2016.)*

		Frequency	Percent	Valid percent	Cumulative percent
Valid	Students hostels	10	13.0	13.7	13.7
	Staff housing	11	14.3	15.1	28.8
	Academic areas	17	22.1	23.3	52.1
	Recreational areas	12	15.6	16.4	68.5
	Circulation zones	15	19.5	20.5	89.0
	Landmarks	8	10.4	11.0	100.0
	Total	73	94.8	100.0	
Missing	System	4	5.2		
Total		77	100.0		

Table 6: What would you consider the worst landscape open space in the UNILAG campus? *(Source: Field Survey, 2016.)*

		Frequency	Percent	Valid percent	Cumulative percent
Valid	Students hostels	31	40.3	40.3	40.3
	Staff housing	12	15.6	15.6	55.8
	Academic areas	10	13.0	13.0	68.8
	Recreational areas	20	26.0	26.0	94.8
	Circulation zones	4	5.2	5.2	100.0
	Total	77	100.0	100.0	

Table 6 shows that 40.3% respondents said they consider students hostel of the university as the worst landscape, 15.6% respondents chose the staff housing provided by the university, 13%respondents chose the academic areas of the university, and 26% respondents chose the recreational areas of the university, and 5.2% respondents chose the circulations zones of the university (roads, pathways, car/bus parks). This table shows that majority of respondents consider the students hostel of the university as the worst landscape of the university, followed by the recreational spaces. This is informative as the respondents are indicating that the recreational spaces still need a lot of work to make them acceptable.

Table 7 shows that 26% respondents said the open space in the university should be reconstructed, 24.7% respondents said general maintenance, 22.1% respondents said more security should be provided, 5.2% respondents said more activities, 13% respondents said greenery. This table shows that majority of respondents said the open spaces should be reconstructed for better.

Fig. 2 shows that 35.1% respondents said they find the vegetation in the university of Lagos most interesting, 28.6% respondents chose the sculptures, 15.6% respondents chose the pathways, 11.7% respondents chose the park/street furniture's, 3.9% respondents chose the lightings. This figure shows that majority of respondents find the vegetation in the university more interesting than any other things.

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Table 7: In what ways can the open spaces on campus be improved with regards to the landscape? *(Source: Field Survey, 2016.)*

		Frequency	Percent	Valid percent	Cumulative percent
Valid	Reconstruction	20	26.0	28.6	28.6
	General maintenance	19	24.7	27.1	55.7
	Security	17	22.1	24.3	80.0
	More activities	4	5.2	5.7	85.7
	Greenery	10	13.0	14.3	100.0
	Total	70	90.9	100.0	
Missing	System	7	9.1		
Total		77	100.0		

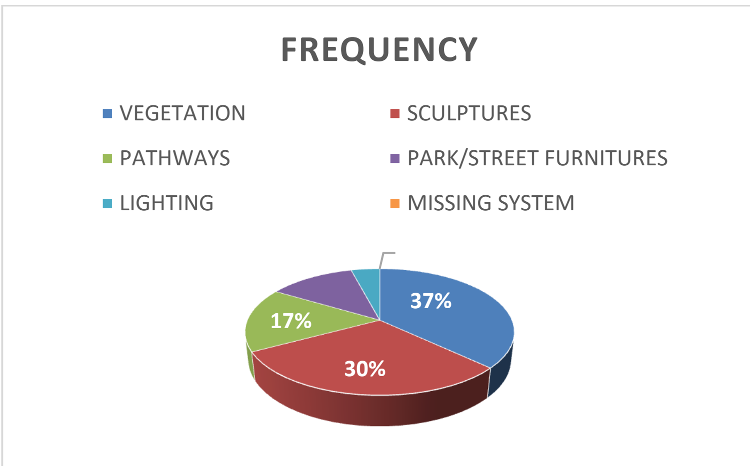

Figure 2: What elements do you find most interesting on campus? *(Source: Field Survey, 2016.)*

Fig. 3 shows that 5.2% respondents said they perceive the open space in the University of Lagos as excellent, 19.5% respondents said it is very good, 49.4% respondents said it is good, and 11.7% respondents said it is bad. This figure shows that majority of respondents perceive the university of Lagos open space as good.

5 CONCLUSION AND RECOMMENDATIONS.

The result of the study shows that the students, visitors and staff of the University of Lagos open spaces generally perceive the spaces as average, indicating that work needs to be done to make them more desirous. The campus' vegetation was perceived as most interesting in the landscape, while a majority of the respondents were of the opinion that the open spaces require attention to restructure them; this was closely followed by those who responded that a lack of general maintenance of the open spaces was a problem. The research found that people's main concern was about quality and that issues associated with poor maintenance

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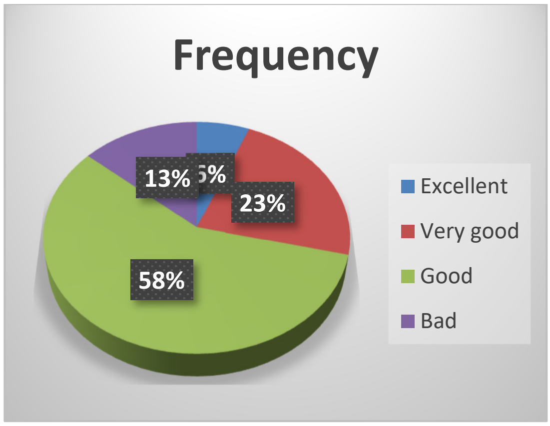

Figure 3: How do you perceive open space in the university of Lagos generally? *(Source: Field Survey, 2016.)*

were the main barriers to using green spaces. The student's hostels' open spaces were considered as having the worst landscape while the open spaces around the academic areas were perceived as the best by the respondents. There was a request for improvement and provision of more recreational spaces on campus.

The study has tried to bridge the distinct university's landscape psychological perceptions and the biophilic philosophical approaches. Drawing upon the literatures studied, the study also used the knowledge of theory and tested the validity of the analysis for design elements as it relates to users' attitudes and behavioral patterns in the open spaces. The various attributes of a biophilic open space design were certainly are key to the connectivity and usability of the various open spaces and the presence of nature as seen from the results. The methodology used in this study using the University of Lagos as a case study, was a combination of observation and interview which were undertaken in the local campus open spaces. Our findings have resulted in establishing a connection between landscape perception of the campus and the usage of the entire open spaces by the users.

The evidence base provided by this study is expected to enable University of Lagos in better planning of its open spaces and ensuring that new development contributes to the creation of a high-quality network of green spaces across the university for a more biophilic impact on its users. The University of Lagos open spaces need to better meet the psychological comfort of the students, staff and visitors through the use of available spaces to experience plants and trees in a more biophilic manner.

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A REPRESENTATIONAL FRAMEWORK FOR SUSTAINABLE DESIGN

ROBERT GROVER, STEPHEN EMMITT & ALEXANDER COPPING
University of Bath, UK

ABSTRACT

Sustainable design is a widely accepted concept, but there is no general consensus on its realisation, as evidenced by the range of strategies in the built environment that fall under the umbrella of "green" design. These vary from technological innovation to empowering social action; which often represents competing world-views, that are often seemingly contradictory or incompatible. Therefore, design for sustainability requires the designer to advocate an ethical or moral stance; and to decide on where to assign value. Despite this, there is no coherent framework which structures the complexity of this field. In this paper, existing models of sustainable development and design are analysed and a new framework that classifies alternative approaches is proposed. The framework presents conflicting paradigms on a continuum, which provides structure to the discourse on sustainable design, allowing building designers to map their own strategic approaches, recognise inconsistencies and reveal potential future directions. Rather than suggesting that sustainability has a single definable outcome; the framework provides a means to contextualise different, yet equally valid, design scenarios.

Keywords: design, green architecture, green design, planning, sustainable design, sustainable framework.

1 INTRODUCTION

Sustainable design represents a significant challenge to the future of architecture. While sustainability is a widely accepted concept, it is a "wicked problem" [1]: it is poorly defined, has any number of possible solutions, and has no "stopping rule" or means to determine success. The seemingly singular common goal defined by the Brundtland Report [2] is open to multiple conflicting interpretations. This variety is evident in the realm of architecture, where practice embodies numerous sustainable paradigms, often in direct competition [3]. This research draws from models of sustainable development and presents a framework that maps and categorises the competing approaches. Rather than searching for an objective categorisation of sustainable design [4], this research seeks a means to represent and embrace plurality. An evaluative framework is constructed; which, rather than attempting to describe a singular idea in a comprehensive manner, can be used to critique possible approaches.

2 MAPPING SUSTAINABLE DESIGN

A range of sustainable development models and frameworks have attempted to organise the complex conceptual arguments and accumulated knowledge of discourse [5]. They can be used to evaluate and guide sustainable development strategy and policy. While there is huge variation, these can be classified by the nature of the information they structure. Nominative models capture a particular concept, attempting to holistically describe either its characteristics or principles. A basic example is the three pillars of environmental, economic and social sustainability (which emerged from the Brundtland Report [2]) and attempt to describe the general conditions for meeting sustainable development. By contrast, evaluative models critique a concept in relation to set criteria [6]. For example, Hopwood et al. [7] analyse competing sustainable agendas through the dimensions of social equity and environmental concern, providing a description of the sustainable development landscape.

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180061

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2.1 Nominative models of sustainable development

Nominative models may be described as either domain or principle based [6]. Domain-based models describe different areas of focus for sustainable action. Connelly [8] develops the "three pillars" concept and considers the contested nature of sustainability as an inevitability. A framework is developed that maps three competing factors that define the breadth of the field: economic growth, social justice and environmental protection (Fig. 1 [8]), contending that any value or approach prioritises one aspect over any other, and contesting the notion of an ideal solution.

Choucri [5] describes a more comprehensive, domain-based framework, which begins by defining a series of themes; the "core-concepts" of sustainable development (Table 1).

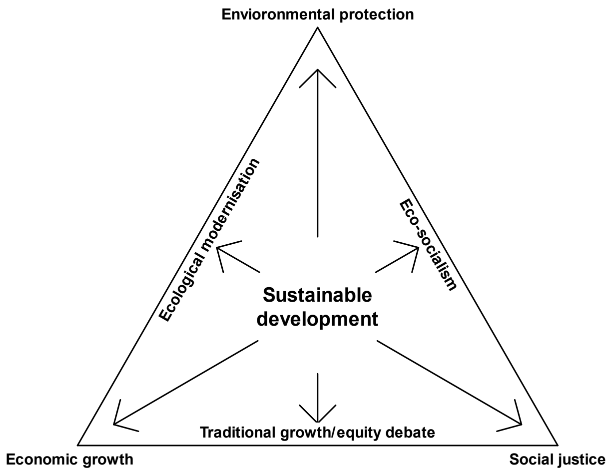

Figure 1: Mapping the three pillars of sustainable development [8].

Table 1: Domains of sustainable development [5].

Demographic domain	Population dynamics Urbanization Migration and dislocation Consumption patterns Unmet basic needs
Energy and natural resource domain	Energy use and source Forests and land uses Water uses and sources Agricultural and rural activities
Technology-centred domain	Trade and finance Industry and manufacturing Mobility and transport
Domains of decisions and choice	Conflict and war Governance and institutions

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Through mapping these domains as a series of slices of an overall circular domain space, concentric circles then represent the dimensions that constitute each domain: activities, problems, technical solutions, social solutions, international responses (Fig. 2). As domains intersect dimensions, a complex model of sustainable development is created that provides a menu of possible practice to enable sustainable development.

Principle-based nominative models describe a particular concept through generalised ideas. For example, Jabareen [9] introduces a cycle of seven distinct principles, each of which are related, to provide a framework for sustainable development (Fig. 3). Equity, global agenda, eco-form, utopia, integrative management and natural stock capital surround an ethical paradox, which lies at the heart of sustainable development. The tension between sustainability and development allows the coexistence of diverse and often contradictory sustainable practices.

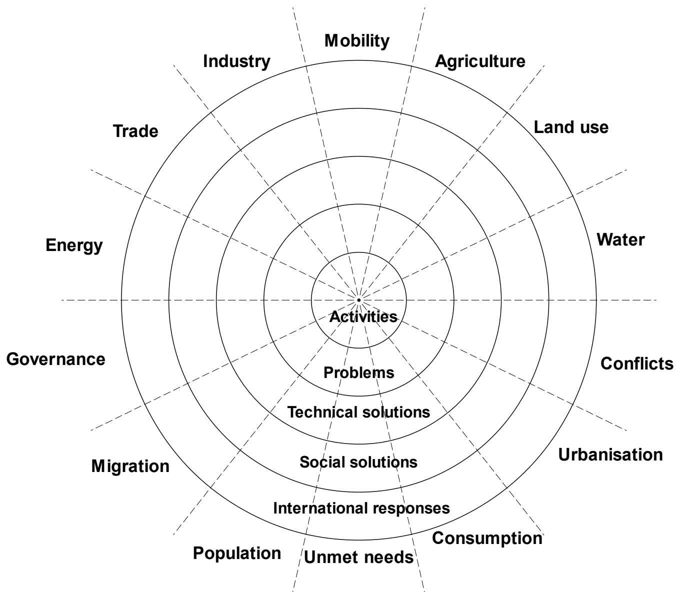

Figure 2: Domains and dimensions of sustainable development [5].

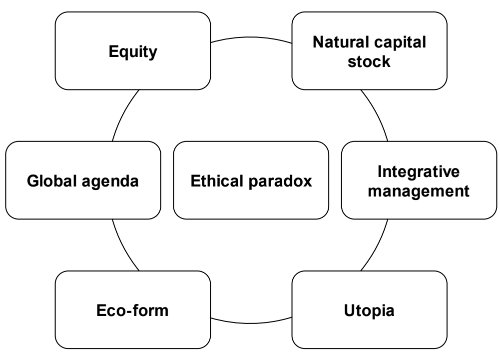

Figure 3: A conceptual framework for sustainable development [9].

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In another example, Haughton [10] defines five equity principles that might govern the formation of sustainable urban environments. These "equity concerns" are inter-generational, social, geographical, procedural, and inter-species; and each sustainable city type (externally dependent, self-reliant, redesigning cities and fair shares) prioritises these differently.

In the field of design, there are a range of nominative models which are both domain-based models [11], [12] and principle-based [13], [14]. The limitations of the nominative approach are the tendency to advocate a particular set of objective criteria that undermine the possibility for discourse, framing the concept normatively. For example, McDonough and Braungart [12] suggest specific rules for instigating the *Next Industrial Revolution.*

Similarly, McLennan [13] describes six principles of respect that should be embodied in sustainable design. While valuable, such nominative models capture only a small aspect of the sustainability debate. Through assuming an exhaustive list of generalisable principles, the complexity of the sustainable agenda is reduced to a series of objective criteria that negate contextual application and critical dialogue.

2.2 Evaluative models of sustainable development

While nominative models seek to provide a comprehensive overview of a particular topic, evaluative models aim to "apply defined criteria to discuss a concept under certain conditions" [6]. For example, the sustainable development debate might be framed through contrasting political paradigms that imply alternative sustainable agendas. Sylvan and Bennett [15] suggest that sustainable development might take three possible approaches to limit human impact on the environment: reducing human population, changing behaviour to lower impact, and technological innovation to reduce environmental footprints.

O'Riordan [16] captures the second and third of these strategies, through the contrasting view-points of eco-centrism and techno-centrism; the former referring to a human-centred approach to developments, the latter focussing on the power of innovation and markets (Table 2).

At its extreme, the *Gaianist* tradition places humankind as an integral part of the natural system, emphasising natural ethics and a nurturing relationship with the environment. This aligns with political agendas that value social equity and communalism. By contrast, the extreme techno-centric position assumes an objective relationship to the natural environment, justifying an interventionist approach. This is characterised by a faith in human ingenuity, market forces and technological innovation to overcome the problems of unsustainability.

Table 2: European perspectives on environmental politics and resource management [16, p. 85].

Eco-centrism		Techno-centrism	
Gaianism	Communalism	Accommodation	Intervention
Faith in the rights of nature and of the essential need for co-evolution of human and natural ethics	Faith in co-operative capabilities of societies to establish self-reliant communities based on renewable resource use and appropriate technologies	Faith in the adaptability of institutions and approaches to assessment and evaluation to accommodate to enviornmental demands	Faith in the application of science, market forces and managerial ingenuity

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Aligning the eco-centric/techno-centric approaches with ethical stances is problematic, as Wilkinson [17] suggests. Eco-centrism, implies a form of environmental stewardship adopting the anthropocentrism explicitly rejected by Gaianist values. Furthermore, Hopwood et al. [7] assert that that socio-economic values do not necessarily align with environmental ones, although they may tend be linked through consistent moral outlooks. Accordingly, in a development of the O'Riordan work, Hopwood et al. [7] restructure this spectrum into a two-dimensional visual representation (Fig. 4). Their model uses perpendicular axes to separate environmental and social outlooks, to frame the sustainable development debate through these two competing dimensions. In turn, the authors plot a range of discourses relating to specific institutions, political movements or schools of thought. The directionality of the axis implies sustainable development tends towards simultaneously increasing equality and environmental concerns towards what the authors term, transformational scenarios.

Despite separating the concepts of social equity and environmental concerns, the authors retain the division between the techno-centric and the eco-centric paradigms propagated by O'Riordan. While the former may imply an interventionist approach, framing the argument as a straightforward challenge between technical and ecological approaches, it has the possibility to undermine mutual coexistence. By implication, value is assigned to the transformative paradigms, which require both social equity and respect for the natural environment, irrespective of particular contextual factors. In the exceptional cases of eco-fascism, with deep ecology and socialist cornucopias, the concepts sit beyond the sphere of the sustainable development debate.

2.3 Models of sustainable innovation

Evaluative models in sustainable design have tended to draw from innovation theory. Commonly, the nature of innovation is classified through the degree of holistic change it addresses [6], [18].

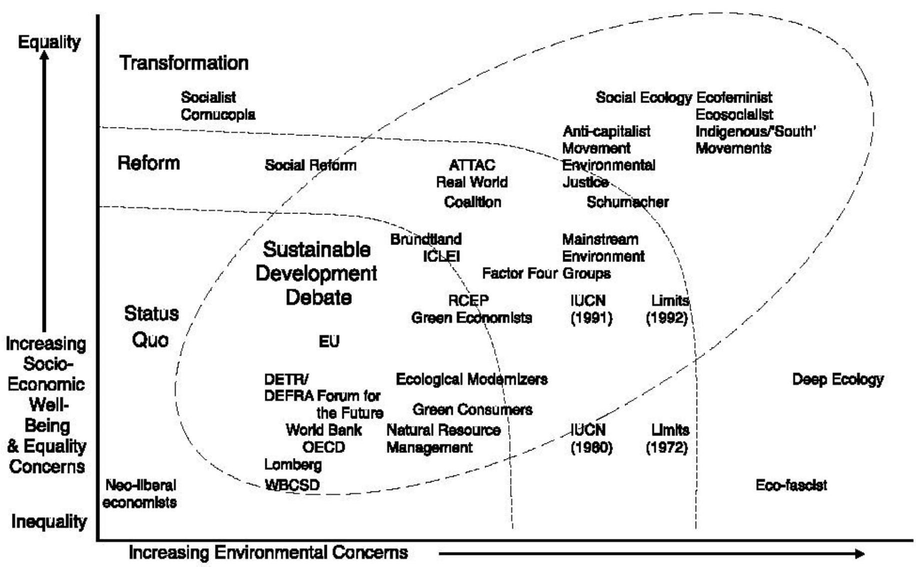

Figure 4: Mapping views on sustainable development [7].

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For example, Vezzoli and Manzini [19] look at the creation of sustainable products to define four levels of intervention representing increasingly "upstream" approaches from the redesign of existing systems to the re-imagination of entirely new life-styles:

1. The environmental redesign of existing systems,
2. Designing new products and services,
3. Designing new production-consumption systems, and
4. Creating new scenarios for sustainable lifestyles [19, p. xi].

At the first level, the redesign of existing systems deals with a neutralisation of accepted patterns of behaviour; at the second, the processes that generate the need for action are redesigned; at the third, the underlying behaviours that create need for these processes are questioned; while at the fourth, entirely new lifestyles are reimagined. At each level, there is a movement away from solution, focussed on technical intervention towards holistic, human-centred changes.

Dusch et al. [6] draw from the hierarchy of Vezzoli, to create a model of sustainable innovation (Fig. 5). They combine models of sustainable development with those in the field of design, to create a "compound" framework.

This framework is structured through the competing eco-centric and techno-centric domains, echoing the work of O'Riordan [16], to develop a matrix of approaches which compare changes in consumption behaviour with technological innovation. Not only does this allow design activities to be classified and compared in this context, but also provides opportunities to reveal the sustainable potential of a particular activity.

For Dusch et al. [6], the creation of new scenarios represents the highest level of sustainable potential, achievable through major product innovation and behavioural changes.

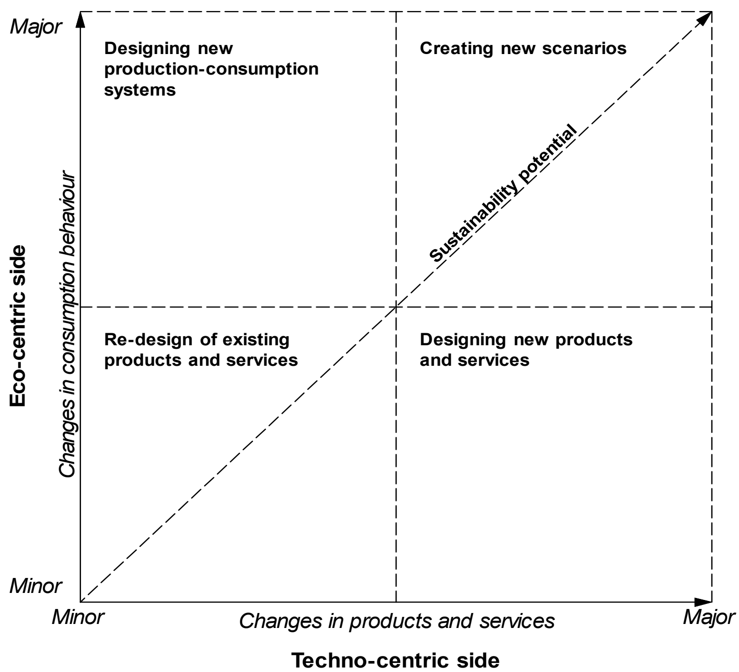

Figure 5: Sustainable design approaches in the context of sustainable development [6].

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Adams et al. [20] describe three primary dimensions which characterise innovation activities across sustainable organisations: the level to which innovation operated across a firm (whether it was isolated or integrated); the organisation's relationship to society (either insular or systematic); and what the particular focus of the innovation was (technology or people). They suggest that systematic, integrated and people-focussed innovation characterises sustainable business.

Ceschin and Gaziulusoy [21] use the dimensions of innovation focus and relationship to society to frame levels of sustainable product potential in a two-dimensions (Fig. 6): On the *y* axis, incremental technological innovation is contrasted with a holistic people-centred approach. On the *x* axis, insular changes that address narrow issues are contrasted with systematic changes that address wider social economic systems. The resultant framework is comparable with Vezzoli's four levels of sustainable design, culminating in the creation of new scenarios at a socio-technical systematic level.

The innovation models considered imply a degree of unilateral consensus that lead towards the common goal of technical and social enhancement. In the cases of Vezzoli and Manzini [19], Dusch et al. [6], and Ceschin and Gaziulusoy [21], there is an implied directionality of design for sustainability, tending toward a combination of innovative product design with more responsible consumer action.

2.4 Mapping architectural design

In the field of architecture, Cook and Golton [22] propose a green architectural spectrum, which frames the polarised concepts of *transpersonal ecology* (a rejection of technology and capitalist politics) with *cornucopian environmentalism* (a faith in the power of the free market, continuous growth intervention and innovation), echoing the approach outlined by O'Riordan [16].

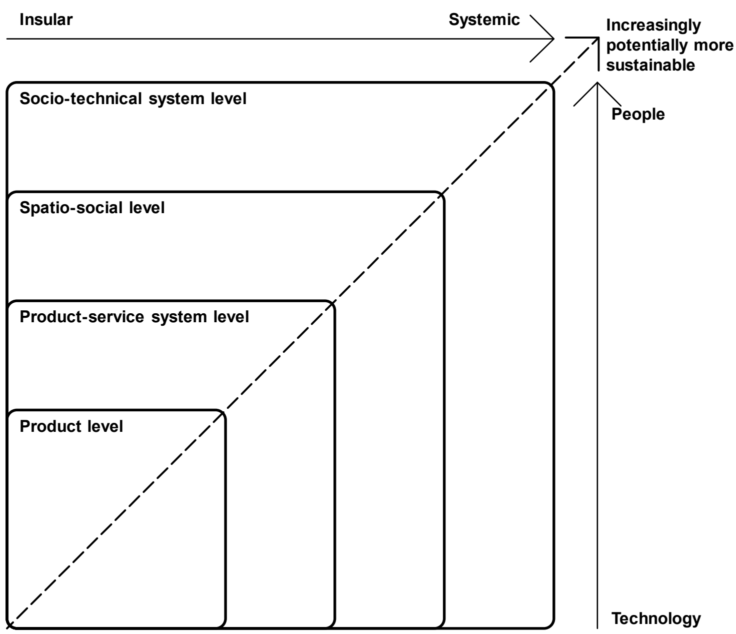

Figure 6: The DFS evolutionary framework [21].

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Guy and Farmer [23] question the universality of "green" architecture and describe six competing "eco-logics", based on a comprehensive literature review. Each eco-logic represents a range of sustainable design values, often at odds with alternative approaches. For example, while the *eco-technic* logic may embrace integrated, intelligent technologies, the *eco-cultural* logic places value on the local, vernacular and low-tech. Likewise, the eco-social logic is aligned with a participatory social approach; however, their eco-aesthetic logic describes an alienating approach which is seen "as an iconic expression of societal values… to inspire and convey an increasing identification with nature and the nonhuman world" [23, p. 143].

In a discourse analysis of the Passive and Low Energy conference 2014, Alsaadani [24] found that the term "sustainable" architecture was used by the profession to refer to a range of concepts, from performance focussed energy-efficient design, to vernacular and holistic interpretations; however, the author concludes that is this flexibility allows architects to generate numerous contextual responses that utilise multiple sustainable design techniques.

As well as being unrepresentative of the realities of sustainable architecture, the search for a notional consensus undermines the social-constructivist nature of environmental problems. Indeed, as Hannigan [25] suggests: "nature, ecology and environmentalism – are by no means fixed in meaning but instead are both socially constructed and contested" [25, p. 126]. It is through embracing this diversity of approaches that conflicting paradigms may act together to achieve particular limited goals, as well as challenge the hegemony of scientific certainty [3]. As Jamison [26] asserts, interpretations of environmentalism are based on contextual factors and *discursive frameworks* which are bound to wider societal values [26, p. 74].

3 DEVELOPING AN ARCHITECTURAL FRAMEWORK

Based on the inadequate application to architecture of existing sustainable models, an alternative framework is presented. The eco-centric and techno-centric dimensions are maintained, representing behavioural (building users) and technological (building fabric) characteristics, respectively [15], [16]. Drawing from Dusch et al. [6], the perpendicular axes represent these contrasting dimensions, in which high-tech strategic approaches are contrasted with low-tech ones on the techno-centric axis; while authoritative versus participatory approaches define the limits of the eco-centric axis (Fig. 7). As Guy and Farmer [23] have suggested, the trend towards product innovation and participatory action [6], [21] does not necessarily represent current sustainable architectural design. In their analysis, some practices adopt intentionally low-tech approaches drawn from vernacular traditions, while others utilise technical enhancements to reduce the need for user engagement.

The axes define four quadrants for potential action that combine high-tech and low-tech approaches with participatory and authoritative ones. Each quadrant is based on its defined relationship between eco-centrism and techno-centrism. The framework allows for centrist approaches, which combine contrasting attitudes toward technology with mixed social approaches. The resulting framework (Fig. 8) is a matrix of contrasting eco- and techno-centric paradigms, and describes eight potential extreme positions at its edges. The range of sustainable architectural practice may be used to populate this spectrum.

The resulting framework provides a map of actual and potential sustainable design strategies in architecture. It allows the range of practice to be mapped and organised to reveal the complexity of sustainable design. This has the potential to guide future sustainable design strategy [5], through realising potential alternative opportunities. It may also be seen as an aspirational tool, where practitioners can identify their location on the axis and work towards a particular approach.

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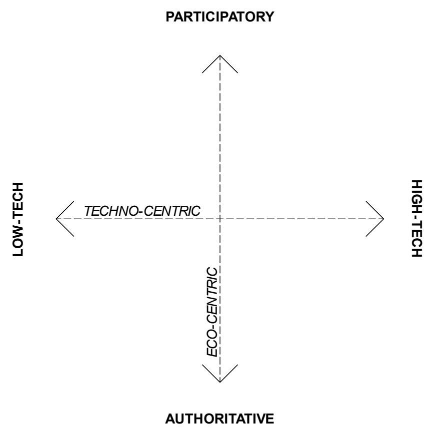

Figure 7: The axes of a framework for sustainable architectural design.

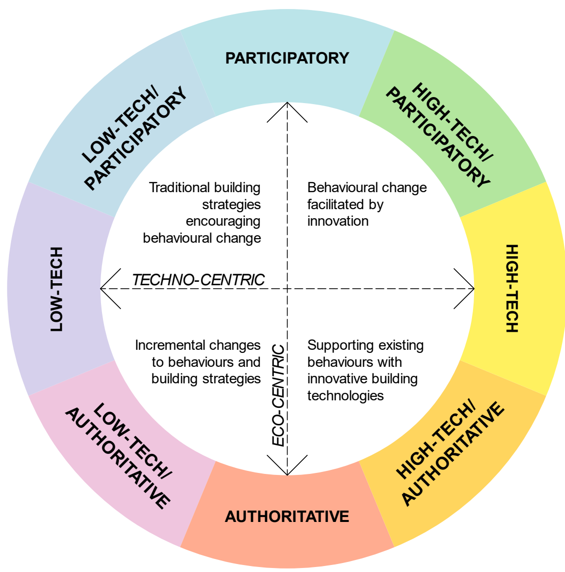

Figure 8: A framework for sustainable architectural design.

The framework defines four quadrants that are aligned with different sustainable paradigms represented in the literature. On the bottom left, the low-tech/authoritative quadrant is defined by incremental changes to behaviour and building strategies. This is loosely aligned with the notion of accommodation defined by O'Riordan [16], which places faith in institutions to adapt to environmental challenges and continue with minor changes to existing managerial and political structures. O'Riordan describes this as "tinkering at the margins" in order to maintain the status quo [16]. Typically, this might involve the piecemeal adoption of technologies in isolation, undertaken on a small scale, with limited changes to behaviours or attitudes.

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The low-tech/participatory sector in the top left is characterised by an approach that adopts simple technologies, often drawing from the vernacular and traditional construction, in combination with user behavioural changes that reduce the environmental impact of lifestyles. This quadrant aligns with the eco-centric and eco-cultural paradigms described by Guy and Farmer [23]. Typically, it is highly contextual and utilises local materials and crafts or seeks environmental stability. Participatory action is important, and it values stakeholders as integral parts of the cultural and environmental context.

In the bottom right corner, the high-tech/authoritative quadrant is aligned with the interventionist and techno-centric paradigms [16]. This approach values innovation through technological progress, focussing on building performance over changes in consumption behaviour. Efficiency and optimisation are prioritised as a means to address environmental problems [23]. Placing the role of technology central to the sustainable cause has been aligned with neoliberal political views which place faith in the free market, the power of human ingenuity and unlimited potential for growth [27].

Finally, the upper right quadrant describes an approach that combines participatory action with technological enhancement. For Dusch et al. [6], this represents the optimal approach to sustainable design, which seeks to transform both behaviours and products. Hopwood et al. [7] describe this radical approach as being used by reformists who argue for a fundamental shift in the structure of society, aligning with the environmental justice movement. Often it represents a decentralisation of power, with a focus on marginal or under-represented communities. In architecture, such an approach might be typified by radical communities that adopt innovative technologies to facilitate low-impact communal living.

Although building on the literature, the proposed framework is unique in its specificity to architecture. Previous design frameworks imply sustainable development and optimal responses combine technical innovation with changes in consumption behaviour (e.g. Dusch et al. [6]) or propose hierarchical intervention structures (e.g. Vezzoli and Manzini [19]). These approaches fail to capture the heterogeneity of architectural design, in which high-tech and low-tech solutions, as well as participatory and authoritative strategies, coexist; where they are equally valid and are contextually determined [23]. The proposed framework captures the range of sustainable approaches and organises the concepts into a coherent visualisation.

4 CONCLUSION

The sustainable architecture framework presented seeks to capture the range of architectural practice and provide an evaluative tool for future design action. If the role of sustainable development is to reduce human impact through changes in behaviour or reducing the impact of those behaviours, differing sustainable design approaches can be captured through the contrasting domains of eco-centrism and techno-centrism. This provides an analytical structure that allows comparison of alternative design paradigms. Existing design frameworks, drawn from innovation theory, could be considered inadequate for architectural design, as assuming a mono-directional focus on sustainable development denies the existence of competing contextualised paradigms.

The value of the proposed framework lies in its capacity to structure the complex realm of sustainable architectural design and allow the spectrum of sustainable approaches to be simultaneously visualised, while exposing opportunities for enhanced future practice. As an analytical tool, it may be used as an educational device, to encourage critical and reflective engagement with sustainable design. It allows the hegemony of technological and scientific knowledge to be challenged, providing genuine alternatives for sustainable design action.

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This paper forms the basis of an ongoing analysis of contemporary design practice in the UK. To validate the framework and assess its relevance to sustainable practice, 26 architects have been interviewed using in-depth, semi-structured techniques [28]. This allowed the researchers to explore emergent themes and uncover motivational factors for sustainable design. A sample was made from three populations: The members of the Royal Institute of British Architects (RIBA) Sustainable Futures Group, practitioners who had won national or regional awards for sustainable design, and practitioners who self-identified as sustainable designers. A "snowball" technique was used to expand the sample within each group.

Interviews were loosely structured using the framework described in this paper and questions focussed on the role of technological innovation and participatory strategies in practice. Guided by the responses of the interviewees, this often took the form of the description of an exemplary building. Each interview was audio recorded and professionally transcribed. Data were analysed through a process of coding, domain analysis, revealing relationships, making inferences, summarising, seeking negative cases and theory generation. This was based on the method set out by Glaser and Strauss [29]. The framework developed in this paper provided analytical categories that defined the subsequent domains used for coding categorisation.

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CIRCULAR CITY: A METHODOLOGICAL APPROACH FOR SUSTAINABLE DISTRICTS AND COMMUNITIES

ANDREA BOERI, JACOPO GASPARI, VALENTINA GIANFRATE,
DANILA LONGO & SAVERIA O. M. BOULANGER
Department of Architecture, University of Bologna, Italy

ABSTRACT

The increasing complexity of urban growth strongly impacts both on the quality of urban environment and on the effectiveness of models for development, requiring innovative approaches to face the related challenges. The proposed position paper reports the methodological approach outlined within a trans-European research project. It aims at defining a systemic urban vision based on resource loops vision in a clustered perspective, overcoming the conventional separation between urban and peri-urban areas. The main scope is to drive a transition from a linear ("take-make-use-dispose") to a circular approach, considering the whole city realm and aiming to close resource loops (in line with EU COM 614/2015, Closing the loop, EU COM 33/2017, Implementation of the Circular Economy Action Plan and Urban Agenda Draft Action Plan on Circular Economy 09.02.2018) while generating new market opportunities and jobs, reducing resources import, decreasing impacts on environment and climate change. The methodology includes the following steps: increasing context understanding, identifying resource flows, using economic potential of existing resources, engaging communities in loops of proximity, facilitating entrepreneur and stakeholders in co-creation of circular economy processes. This paper explains the positioning of the research within the state of the art; it describes the applied methodology and related expected outcomes, defines the main related initiatives and implementation models. This study identifies regenerative corridors (RC) as potential effective drivers to overcome the conventional separation between urban, peri-urban and rural areas in the EU context, investigating their relations and identifying driving factors for a circular equalized development among these different urban zones. This paper also reports on the impact indicators and the replication potential of the proposed systemic approach.

Keywords: circular city, regenerative city, urban corridors, systemic approach, urban scenario, closing loops, resources, urban metabolism.

1 INTRODUCTION

During the last years, the idea of "Circular City" is emerging in the scientific literature as an interesting field of debate fed by a number of open challenges that the cities of tomorrow will be facing: scarcity of resources, economic crisis, lack of social identity, innovation and availability of technologies. However, the topic is far from having achieved clearly defined boundaries especially when case studies meet the real context conditions. Thus, the topic is evolving according to a turning point of the transition period most of contemporary cities are experiencing [1]–[4]. As stated many times by the EU in the last few year's [5]–[7], cities can be defined as the keystones of the European well-being for economic strength, wealth and social opportunities for the future. The population growth is indeed increasing the urban density year-by-year, feeding a complex interaction of parameters dealing with urban management and sustainability. Waste management, energy demand peak, traffic congestion, air and water pollution, lack of identity, fuel poverty are some of the main problems challenging the city authorities in a long-term perspective [8], [9]. Among them, some specific recurring elements, creating the context and background for suitable solutions are of particular interest for this research:

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180071

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- the acknowledgement of the European decrees – 2010/31/EU [10] – imposing a substantial reduction of emissions (20% before 2020 and 40% before 2030) and an overall improvement of environmental conditions and urban energy savings;
- the pressure of the global market that continuously proposes new ICT technologies and devices to enable citizens' connection to services and tools;
- the great amount of existing buildings and neighbourhoods affected by obsolescence phenomena related to energy demand, indoor/outdoor quality, resource management, fuel poverty;
- the lack of long term planning visions to tackle the urban sprawl;
- the constant growth of land use and the related effects on urban climate conditions;
- the constant rise of resources demand connected with population growth;
- the digital revolution linked to social networks that may produce unpredictable effects on social relations and behaviours as well as on the use of urban spaces [11].

Mitigation and adaptation measures to climate changes as well as new ways for resource management are addressed, in the scientific literature [7], [8], [11]–[13], as some of the most challenging and urgent issues to support the transition toward low-carbon cities assuming that the urban metabolism is quickly approaching a point of no-return.

Hence, cities represent an important field to experiment sustainable and resilient solutions based on innovative technologies and enablers (both ICT or not), becoming the core of the debate about technological implementation, resource management and urban evolution.

The present work deals with the need to find new stripes for circular resource management and the definition of a new design strategy for regenerating the existing built environment in a more sustainable, resilient and smart perspective.

2 ANALYSIS OF URBAN CIRCULAR APPROACHES BEYOND THE STATE OF THE ART

According to a qualitative literature analysis, the concept of "circular city" started to be associated with products development, monopolistic competition and industrial organization [14] at the end of the last century, in contrast with the linear city model proposed by Hotteling [15]. At the beginning of the century, it was associated to different ways of planning cities: from ecology, to transport field, energy production and management and to people involvement into governance processes.

Only in recent times, the concept of circular city is associated with resource flows and management in cities, identifying a way of use and re-use resources [16] connecting the concept of urban environment with the idea of circular metabolism. This new approach overcame the "take-make-dispose" paradigm addressing the priority to re-use.

According to Kennedy et al. [17], urban metabolism can be defined as "*the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste*". In this framework, the circular city is strictly linked with the concept of "zero-waste city", becoming one of its synonym [18]. According to Zaman and Lehmann [18], the majority of actual cities propose a linear metabolism: resources are produced, used and finally disposed (as solid waste, wastewater or emissions to the atmosphere). While, "*in a zero-waste city material flow is circular, which means the same materials are used again and again until the optimum level of consumption. No materials are wasted or underused in circular cities*" [18]. This reflection led the concept of circular city becoming more and more strictly associated with the

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concept of circular economy. According to Kirchherr et al. [19], these issues are mainly related to reducing, reusing, recycling and recovering activities (4R) in cities even if "*it is oftentimes not highlighted that circular economy necessitates a systemic shift*". However, in the same research, it is highlighted how the impacts of circular economy are often linked with economic prosperity and less with sustainable development.

The study presented in this paper aims to go beyond the economic understanding of the topic assuming a systemic perspective that combines several aspects: circular economy and urban metabolism creating new interactions level including a plurality of stakeholders and transforming users in prosumers; including not only resources but also culture and society; creating a circular governance structure able to start from pilot intervention to their analysis of impact and replication in other contexts. Within this perspective, a circular city is not only a resource matter but a more comprehensive approach permeating all levels of the urban system.

3 METHODOLOGY OF RESEARCH AND MODEL APPROACH

The model is based on a multi-disciplinary and circular approach for the transition of urban and peri-urban areas toward regenerative cities: cities able to consider their impacts on the environment and the society while regenerating resources in a resilient perspective [20], [21]. Therefore, the proposed systemic model strengthens the relations among actions, actors, spaces and resources and it can act as an engine able to regenerate and to improve the mutual exchange between different areas of the cities.

The research group of the Department of Architecture – University of Bologna is studying this approach, expanding a model developed for historic city centres under the umbrella of "ROCK project" – Regeneration and Optimization of cultural heritage in Creative and Knowledge cities (EU-Horizon 2020 funded project; G.A. 730280). In ROCK project a circular model has been proposed and applied in several European cities with the aim of finding new ways for valorise cultural heritage while preserving its integrity and symbolic force. However, several topics can be addressed through a comprehensive circular methodology.

The model approach is based on integrating two interlinked concepts: the creation of resilience corridors able to connect different parts of the city (urban and peri-urban; historic downtown and peripheral areas, etc.; the economic centres to the satellite areas) and the creation of innovation hubs, nodes of innovation where specific actions can take place. The objective of the proposed methodology is to guide the transition towards the creation of regenerative cities, as defined by UN Habitat: "*cities designed to be resilient by being energy efficient, low-carbon, and increasingly reliant on renewable energy sources, taking care of resources, recycling and reusing waste, using water, land, and energy in a coordinated manner and in harmony with its surrounding hinterland in support of urban and peri-urban agriculture*" [21]. Furthermore, the model aims to enhance the process of regenerative cities by including multi-layered approaching and monitoring targeted to balance resources, energy, people flows, built environment, communities in a mix able to improve the presence of life quality, smartness and sustainability. It aims to develop an integrated approach that goes beyond the closing of resource loops, as defined by the EU COM 614 [22], to meet a deeper urban metabolism, where resource, energy and technological flows are balanced with a social approach based on the development of local ecosystems of stakeholders, innovative enterprises and integrated value chains. The two main aspects of this approach are:

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1. the development of linkages, interconnectivity and interdependencies in urban systems (energy, water and food and material provisioning systems);
2. the need for integrated holistic approaches across these sectors recognizes the linkages and aims to better respond to the need for integrated policies and implementation mechanisms with systems optimization through an approach to counter silo-thinking between the urban sectors, transforming the inefficient system and moving away from out-dated single-purpose solutions.

The aim is to support the shift of urban metabolism from its current wasteful linear system into a resource-efficient circular system. Yet creating a circular urban model implies connecting "systems" that were initially separated by technical, organizational and institutional solutions and changes ("multiple innovation processes"), to be adopted and adapted [23].

It's very important in the regeneration processes to overcome the "silos" approach and to connect the different systems involved or related to these processes. The model starts from the identification of the specific local systems articulated into:

- System of actors, as defined in the lists of Ecosystems of Stakeholders to list and prioritize the transformation needs, the collaboration pathways, the opportunity creation;
- System of places, starting from pilot areas and understanding their relations with the whole urban contexts, circulating solutions, tools, strategies and results of experimentation, to foster the replication of the most effective ones in similar contexts;
- System of initiatives (bottom-up and top-down; collaboration, sponsorship, partnerships, etc.) to promote creativeness and cultural production from different sources, combining them in common projects of regeneration;
- Systems of resources (physical resources, financial resources, human capitals) to promote a circulation of flows, overpassing the linear processes in the circular city, from extraction to waste, replacing them by circular processes and that lasting connections can be made between flows. These flows – such as goods, people, food, waste, water, wildlife and air – are the city's metabolism that allows the city and the economy to function.

Given these considerations, the model is based on a circular step-by-step approach, made of eight complementary phases of application (Fig. 1).

Phase 1 Analysis of the context. The context is investigated according to a multiple set of different aspects (resources, people, energy, environmental conditions, economy, etc.) to which properly identified KPI are related. The aim and the major output of this phase is the creation of an ID card of the Resilient Corridor and a first GIS-based database for the further development of scenarios.

Phase 2 Identification of the circular innovation nodes. This phase aims to define the location and the nature of the specific sites where pilot actions can firstly take place within the corridor.

Phase 3 Set a local ecosystem. Innovation hubs inside the resilient corridor are based on the creation of local ecosystem of stakeholders. Involving the major players of local communities with relation to needs and on-going activities at local and city level is a crucial action to deliver a modal shift.

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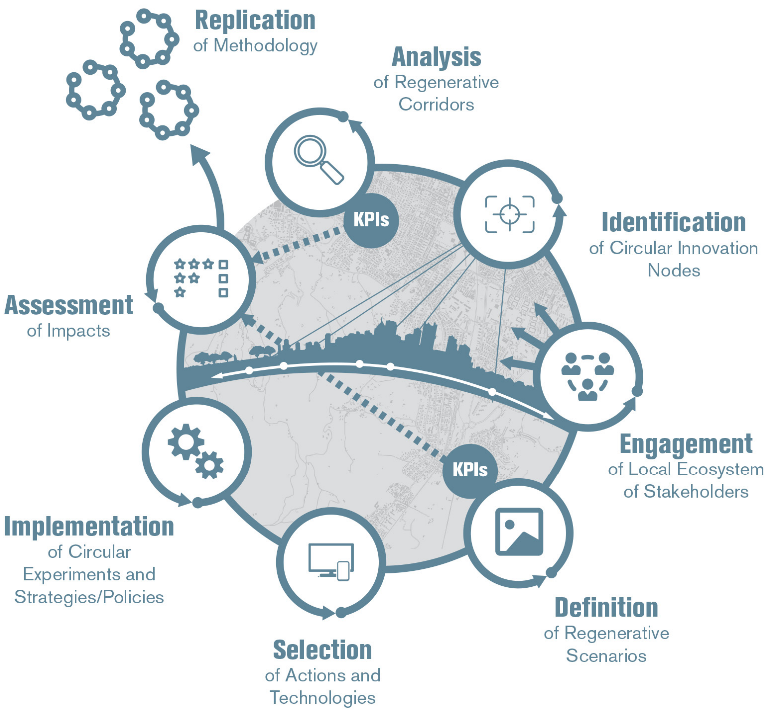

Figure 1: Model steps.

Phase 4	Scenarios generation and value chain proposition. According to the understanding of the local context given by phase 1 and 2 different scenarios can be simulated on an action-based perspective. Thus, scenarios can be drafted changing different sets of actions on the same timeframe in order to understand which set is able to optimize synergies and impacts with relation to the expected results.
Phase 5	Technological solutions and implementation plan definition. This phase is aimed to define which specific actions can be implemented in the first pilot application and which ones can be applied in further phases.
Phase 6	Implementation of actions and experiments. This phase is intended as the real application of selected actions.
Phases 7 and 8	Evaluation and replication. The delivery of the process is accurately evaluated both during preparation and implementation according to specific indicators in the entire demonstrator and at the same time observer cities are involved in assessing the replicability potential.

4 RESILIENT CORRIDORS AND INNOVATION HUBS AS FIELDS OF APPLICATION

The proposed model foresees the implementation of different actions, according to the following scheme:

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- Actions inside innovation hubs. aiming to collaborate with the already existing activities, the model will implement within the innovation hubs a panel of actions and technologies to enhance the potentialities given by urban metabolism and close the loops inside each ring with an impact on the whole area. The choice to work with already existing nodes of activity ensures the access to local stakeholders and community and the sustainability in the long-term perspective.
- Transversal actions on the resilient corridor. A set of actions and technologies are foreseen all along the corridor with the aim to create new connections among the Hubs and toward the entire city and for starting new circular approaches between the Hubs and the city based on making the territory regenerative with relation to energy flows, people flows, resilience, sustainability, energy efficiency.

The model intends resilient corridors as physical spaces, framed by the presence of natural or artificial infrastructures (such as streets, railways, rivers, etc.), connecting urban and peri-urban areas. Inside resilient corridors several innovation hubs can be identified: spaces where existing activities are ongoing (e.g. innovative districts, cultural activities, bottom up processes, etc.) and where testing the implementation of innovative actions aiming to close resources loops (e.g. water, food, waste, energy, etc.).

The connection among innovation hubs can support the creation of new value chains strengthening relations among actions, actors, spaces and resources, that act as an engine to regenerate and improve the mutual exchange between different areas of the cities according to a systemic approach.

The resilient corridor is intended as a primary pilot area of intervention where actions (social, technological, environmental) can be applied on specific areas named innovation hubs (Fig. 2).

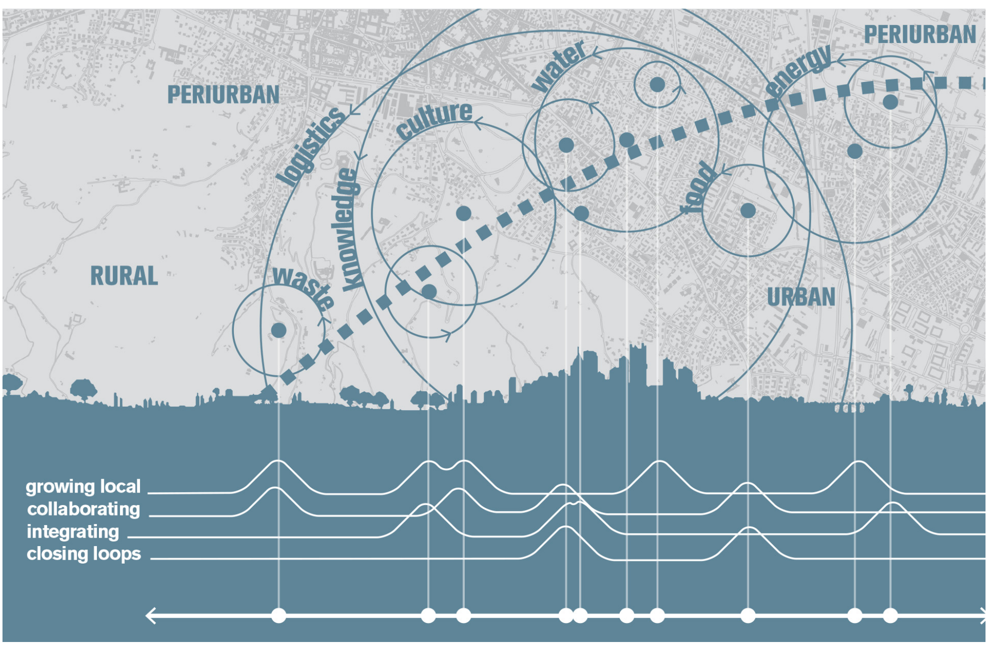

Figure 2: Resilient corridors and innovation hubs.

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The single activities can be discussed with the local ecosystem of stakeholders.

The corridor concept allows the development of designs that engage issues connected to the territory.

Re-use of public spaces and building regeneration represent a key action to reduce land consumption and improve the quality of built environment while hosting ecosystem services as an integral part of the circular development model including:

- reduction of materials use, of new land and buildings;
- reuse and shared use of existing goods with new functions;
- maintenance of existing good ensuring longer life;
- energy recovery;
- re-use of specific local knowledge for valorising the differences in the territories.

5 IMPACT ANALYSIS AND KEY PERFORMANCE INDICATORS

A number of impacts grouped into layers are the result of the model application. The model uses complementary qualitative and quantitative methods (participants observation, informal, interviews, focus groups and mini surveys) in order to delineate, explain, and understand the complex nature of circular urban system approach; to grasp highly interactive social situations – considering the participation of vulnerable groups (minorities, elderly and socially marginalized populations, understanding people's values, motivations and behaviours; and to assess the project's impact on its various audiences. Thus, different layers of impacts and related performance indicators can be identified:

- impacts linked with the model application in urban context which leads to policy-driven indicators;
- impacts linked with the application of actions leading to innovation –driven indicators;
- impacts related with people involvement and participatory approaches leading to social-driven indicators;
- impacts linked with the success of the process.

According to the purpose of this paper, an example of indicators are provided in Table 1.

6 CONCLUSIONS AND FOLLOWING DEVELOPMENT

This position paper represents a first work toward an innovative and systemic model for regenerative cities aiming to include several steps. The paper describes the methodological backbone of the study and the implementation model as well as the preliminary application fields according to the general structure. Its main objectives are strictly aligned with the 17 Sustainable Development Goals [24] and mainly with the urban related one, addressing the following tasks: "*support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning; by 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement*".

The further development of the study may include in the future:

- a roadmap for regenerative and circular cities and the structure of an integrated management plan for resilient corridors;
- a guideline for closing resource loops in specific demo cases;

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Table 1: Example of indicators.

Expected impacts	Indicators
Measurable increase of the regenerative capacity of urban and peri-urban areas	Number of projects including urban and peri-urban areas proposed by communities
	Decreasing % of carbon footprint of the regenerative corridor (CO_2e/cap)
	Increasing % of re-use and recycling (spaces and resources)
	Number of projects from communities working on re-use and recycle
	Decreasing % of land use around regenerative corridors
New cooperation opportunities in local governance innovation to response to stakeholders needs	Increasing in % of active and visible participation of women and ethnic minorities in initiatives and activities
	Number of multi-actor (PA/citizenship/suppliers) agreements for the management of corridors as common goods
	Number of collective initiatives under the agreement
Boost creativity and entrepreneurship related to circularity and regenerative processes; Promoting local growth	Increasing in % the number of short-cut circular ancillary business along the corridors
	Increasing in % of real estate value and revenues in the demonstration areas
	Number of initiatives promoted by local association about circularity of resource flows
Measurable reduction of materials, natural resource consumption and environmental footprint in urban and peri-urban areas	Number of circular experiments along regenerative corridors promoted by living labs (LLs)
	% of reduction of resources consumption along the corridors during experimental phases
	% of reduction of resources consumption after pilot phase completion
	Decreasing % of carbon footprint of the regenerative corridor (CO_2e/cap)
	Increasing in % of new data about circularity and regenerative capacity

- a guideline for citizen participation and co-design inside innovation hubs;
- a set of enabling technologies to boost the process;
- a more detailed set of impacts and related key performance indicators emerged and monitored during the experimental process.

Once completed and successfully tested, the model can bring regenerative cities to benefit the environment and natural ecosystems; drive the local economy; improve neighbourhood cohesion and health; increase their own resilience and enhance participatory decision-making.

Nonetheless, a number of barriers are embedded in the current political, financial and social institutional framework can be identified: the biggest obstacle is often represented by

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the limited political horizon characterizing the public administration, however also the lack of systematic framework for stakeholders engagement to build effective public participatory process can become a barrier to achieve a wide consensus and an acceptable level of public awareness around the main scope of the project. A systematic analysis of potential barriers and obstacles certainly represents the very next step of the study in order to set adequate guidelines for supporting the process at political and societal level.

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INNOVATIVE CIRCULAR SOLUTIONS AND SERVICES FOR NEW BUILDINGS AND REFURBISHMENTS

GAETANO BERTINO, FRANCESCO MENCONI, ANDREA ZRAUNIG,
EDUARDO TERZIDIS & JOHANNES KISSER
Alchemia-nova GmbH, Austria

ABSTRACT

The housing sector is responsible for more than 50% of global resource extraction, about 50% of world energy consumption, 1/3 of water consumption and furthermore generates about 1/3 of all produced waste. A new, circular approach is needed to enable better decision-making on the selection of innovative architectural solutions for all phases of a building's life cycle. The current building sector's business model must be redesigned to include the application of new and improved methods, solutions and innovative services, and advance a positive transition from a linear economy to a circular economy. We will present the circular interventions carried out on a centenary building located in Vienna in the framework of the HOUSEFUL project. HOUSEFUL is an EU-funded initiative with the objective to develop and demonstrate integrated circular services, focusing on the optimal management of resources throughout the life cycle of new or existing buildings. The demonstration will include technologies to circulate all process flows while reducing the overall energy demand. These technologies will be offered as integrated services to produce treated rain and wastewater for internal reuse, the generation of renewable energy from biogas, compost production combined with urban gardening and for the use of nutrients in a greenhouse. The design of more efficient processes, such as green walls, innovative conservatories, building-integrated solar thermal and photovoltaic panels will improve building energy efficiency. All process flows will be intensely monitored to ensure safety and collect data for further replication cases. The solutions will also include the use of sustainable and upcycled materials and the implementation will be based on the principles of reversibility and de-constructability. The final services of the building will be elaborated in co-creation workshops with a multitude of stakeholders. Additional service-oriented modelling facilitates replication for the transition to the circular housing sector.

Keywords: circular economy, service-driven business models, nature-based solutions, innovative use of secondary resources, technological innovation, resource and energy efficiency.

1 INTRODUCTION

The transition from a linear to a circular business economy is being implemented at an industrial scale in Europe. Many referenced case studies and innovative projects are focused on the innovative design of products, smart production lines in industry and energy efficient processes. However, this transition has not yet taken place at all levels of the housing sector (energy, water, waste and materials). Most of the time the circularity only focuses on one of these levels. For that reason, a new circular thinking approach is required to enable better decision-making on the selection of circular solutions at the different, or various levels for all the different stages of a building's life cycle to attain optimal building functionality and maximise the reuse of resources in a co-creation process [1].

Meeting the challenges outlined in Fig. 1 requires the redesign of current housing business model, creating new methods for the evaluation of the circularity level in the housing sector while co-creating new solutions and services for its improvement. The transition from a linear to a circular business model in this sector will contribute massively to establishing a low-carbon urban economy in future "green" cities, and the reduction of waste and GHG emissions, recognising the COP21 objectives and the goals proposed by the 2030 Agenda for Sustainable Development (United Nations, 2015).

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180081

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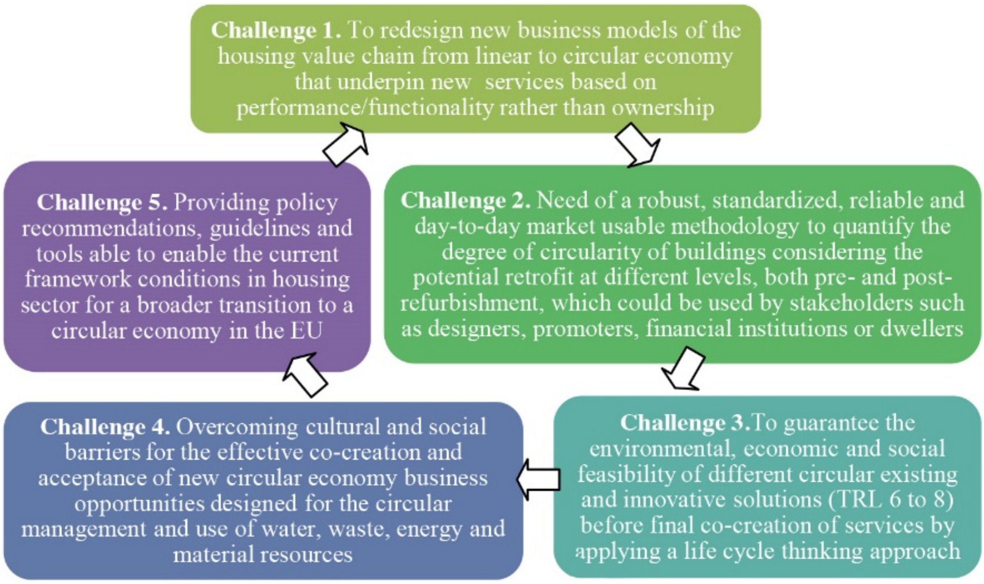

Figure 1: Main HOUSEFUL challenges addressed for a circular housing sector.

The main goal of the HOUSEFUL project is to develop and demonstrate an integrated systemic "service" composed of different circular technical solutions in the current housing value chain. The HOUSEFUL service will aim at the circular management and efficient use of water, waste, energy and material resources for all the stages of European building's life cycle and will be presented as an on-line "Software as a Service (SaaS)", enabling the replication of proposed circular solutions at EU level: renting, leasing, customer service, capacity building service, and various combination thereof. The integrated HOUSEFUL service and proposed technical solutions will be demonstrated at a large scale in four representative European residential buildings (frontrunner buildings) characterised by variations in climate, social and legislative/organisational conditions, as follows: "DEMO 1" in Sabadell, Spain – a building constructed in the 1960s to be refurbished for social housing; "DEMO 2" in Terrassa, Spain – a to-be refurbished social housing estate built in the 1970s; "DEMO 3" in Vienna, Austria – a centenary building designated for both private and commercial use; "DEMO 4" in Vienna, Austria – a new social housing building constructed in 2017.

The buildings were selected with regard to their spatial and geographical distribution which would guarantee the collection of data on the feasibility and replication of solutions across differences in social, cultural and current practices on housing, differences in national regulation regarding construction and refurbishment, and common European building archetypes. Further considerations related to variations in scale and number of dwellers per building, climate-oriented differences in characteristic and typologies of residential buildings, and common challenges shared by construction companies, related professionals and regional/national housing agencies. The frontrunners will accordingly act as references for replication activities of proposed solutions with a further ten so-called "Follower" buildings to be identified during the first year of the project execution.

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2 VIENNA CENTENARY FRONTRUNNER BUILDING

DEMO 3 is a privately-owned residential building which includes an office, laboratory storage-basement, garden and residential space. This building reflects a typical building category of Central European centenary buildings that were not destroyed during the war and it is due for substantial refurbishment. Main demo objectives are to demonstrate the feasibility of HOUSEFUL services offered to the users (and possibly the neighbours) of the building, while at the same time reducing the energy demand and closing water and nutrient cycles by recovering water and nutrients from wastewater and organic waste. This will be achieved by structural modifications with regard to pipe installations, roof structure, facade change, integration of winter gardens, and garden infrastructure. Main HOUSEFUL solutions will also involve the use of circular materials to almost passive house standards but including new functionalities on facades and the roof such as nature-based solutions for wastewater treatment. Post renovation energy requirements will be catered for by photovoltaics and the incineration of biogas produced directly in the building. All the organic waste materials that are produced in the building will be used for biogas generation and in-vessel composting. Wastewater will be treated in plant-based water filtration and purification systems allowing for the dissolved nutrients used as fertigation in urban farming applications, perhaps even in a greenhouse structure.

2.1 Technical solutions

In detail, the technical solutions can be grouped according to the resource considered, accordingly: materials, water, waste and energy vectors.

Additionally, the integration of all the solutions must be considered for the realization of control, analysis and management services. Fig. 3 above shows the main water, bio-waste

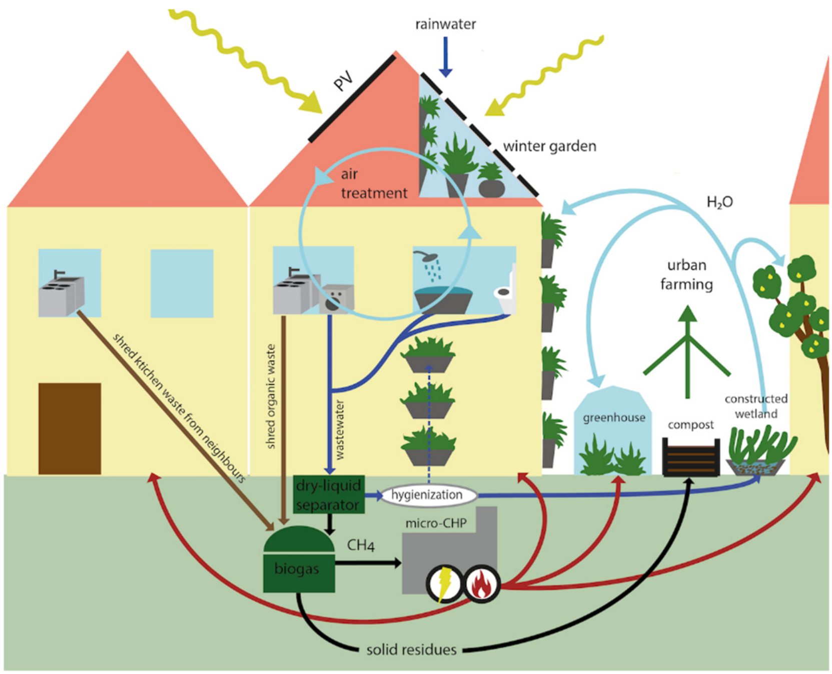

Figure 2: Main water/waste/energy flows HOUSEFUL solutions.

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and energy flows foreseen within a building, together with a representation of the technology behind the solutions.

2.1.1 All resources management

The different HOUSEFUL circular solutions in the field of materials, water, waste and energy will compose the integrated system service that will be driven and promoted as a “Software as a Service (SaaS)”, aiming at evaluating building circularity while offering different circular solutions as services to increase it for all stages of building life cycle. It will be created to support actors from the housing value chain to redesign their business model according to circular economy principles and it will be a user-friendly circularity tool for professionals but also for owners, dwellers and tenants will also be delivered to raise awareness of circular economy models.

A business plan of the HOUSEFUL model will be developed to provide circular services and products as new leasing and/or renting conditions to the housing sector. Special attention will be paid to the leasing and/or renting models for such physical solutions developed (as modular facades). The policy restrictions and safety checks will be reviewed to overcome major risks in the new commercialisation of solutions under new circular business models adapted to services.

The SaaS will offer two main features. The first is the a “circularity tool” to quantify the circularity level of residential buildings. Users will be able to work with data and calculation methods at two defined levels: (i) a free-access level with clearly defined and adapted key performance indicators such as water reuse ($m^3/m^3 \cdot day$), total primary energy demand ($kWh/m^2 \cdot yr$) and share of renewable energies (%), etc.; and (ii) a pay-per-use interface with consumer specific oriented results, where different interventions will be suggested to enhance the circularity of the building and quantifying the effect of these interventions on the building. The circularity tool addresses the current information deficit by proposing a set of clearly defined and measurable indicators for the assessment of the environmental performance of residential buildings. The second feature is an interactive results sharing platform created with the primary aim of promoting the co-creation of new circular economy business opportunities by stakeholders in the housing sector. The platform will contain successful circular solutions and services demonstrated in the building, together with other successful experiences collected to promote the replication of these initiatives and facilitate the collaboration among stakeholders.

SaaS will underpin the housing value-chain and support the optimisation of its value proposition, clients, activities, partners, cost structures and revenue streams. Presently, some circular products do offer repositories for greener building design [2], or even new brand methodologies (such as Level(s) [3]), but none offer the combination of both. The SaaS service will not only evaluate the building circularity but offer explicit solutions to optimise it in a service mode based on performance/functionality rather than ownership.

2.1.2 Materials

Under HOUSEFUL, a solution to many problems affecting the construction industry (e.g. excessive waste and high costs [4]) will be provided in a digital format, focused on sharing data related to materials used in new and existing buildings, and their impacts on the environment. As part of this solution, Building Information Modelling (BIM) and the so-called “material passport” will be provided jointly as services driven to increase productivity and efficiency within the built environment, allowing for better decision making along the value chain from design to construction/refurbishment, operation, maintenance and demolition.

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The material passport will give an overview of products, components and materials used in the existing construction objects, updated in sequential years with financial valuations and able to provide advice on the architectural possibilities available to safeguard existing materials, and even re-incorporate their value into new building functions.

To better utilise local materials and thereby contributing to circularity by shortening the cycle, the HOUSEFUL intends to source over 50 types of building materials (existing or new commercial products) from secondary material platforms, databases and local producers, contributing to the debate on quality, origin and potential material reuse at local scale. The search will be focused on EU certified products, clearly contrasting technical and environmental specifications to allow for a complete material characterisation and the calculation of the building's potential impact along the building's overall value chain, namely manufacturing, design, construction, use and demolition phase. The results will then be included in a "Circular materials database" which will include, not only certified products (wood, steel, etc.), but also the cost and supply conditions associated or linked to these products. Some of these seemingly "more circular" products will be widely defined and detailed regarding potential uses, such as those contributing to the improvement of energy efficiency, or other such as certain paints, that may contribute to an improvement of indoor and outdoor air quality. The analysis of potential uses of certified building material is essential for the improvement of building circularity and this will furthermore facilitate the potential modelling of building characteristics and a provide successful quantification for impact analysis. Furthermore, the results can provide new circular business opportunities at local scale.

2.1.3 Water

Although water reuse is an established practise in some European countries, obtaining reclaimed water from the wastewater treatment plants, this practice is limited by the distance from application sites and the risk of industrial pollutants potentially present in centralised systems. Reclaimed water from wastewater treatment plants is usually recovered from tertiary treatments after the nutrients have been removed. However, considering that more than 70% of water reuse is intended for irrigation in agriculture, these beneficial nutrients should ideally remain in the water. In HOUSEFUL, rain-, grey- and blackwater will be treated in Nature-Based Solutions (NBS) to reclaim water for reuse after disinfection by commercial UV/O_3 to flush toilets, laundry or irrigation. The feasibility of the NBS technologies will be demonstrated within the project at building scale.

Green facades for the treatment of grey- and rainwater will be constructed at semi-pilot and pilot scale. The façade structures consist of more than 70% construction and demolition waste (CDW) and are furthermore designed for circular building with innate modularity and upcycling character. The outer layer will contain plants selected for rain- and greywater treatment and will also provide micro-climatic benefits, and plant/food production services.

An indoor vertical wetland ecosystem will purify the liquid fraction from un-segregated domestic wastewater. A vertical set-up combined with a horizontal subsurface flow (HSSF) was developed as a prototype for indoor use and has demonstrated functionality in a real environment with a greywater flow of up to 2 m^3/day. Offering such greywater treatment solutions to households or touristic facilities is greatly constrained by the need for a secondary plumbing system. Accordingly, HOUSEFUL plans to separate the liquid from the solid fraction of conventional wastewater and to then treat the liquid fraction in a HSSF, in an attempt to combine the lower levels of the treatment area with the production of edible plants. In addition to being aesthetically pleasing, the green wall supports air-purification and furthermore offers a home-level food production service.

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Similar vertical constructed wetland will be integrated into building adjacent winter-gardens, designated for construction across all the building floors. The winter-gardens will function passively and autonomously and treat air channelled from inside the building, together with rainwater/treated wastewater.

The nutrient-rich wastewater will also be used in circular aquaponics and farming systems. Aquaponics will recirculate water from fish tanks through a vegetable culture bed. Nutrients from the fish waste feed the plants, and the plants filter the water to keep the fish healthy. The two main components of the system are the fish tanks and the grow beds with a small pump moving water between the two. The water passes through the root system before draining back into the fish tank. The plants take up the nutrients (fish waste) for their own growth and doing so, purify the water for the fish. The main benefit from a system like this is the ability to grow plants and breed fishes in one system with a relatively low energy consumption, fast growth rates and high yields. Eliminating the need for weeding and tilling of soil, plants are naturally fertilized and no wastewater run-off into the recirculating system.

A soap-bubble-insulated greenhouse (consisting of a foam generator filling a double walled greenhouse with soap bubbles) will provide for stable inner-greenhouse climate at night. The insulation can then be removed during day time to gather passive solar heat and allow light in for plant growth. Growing food in greenhouses during the winter may still not be economically viable due to the high cost of heating and the low thermal resistance of standard greenhouses, but the soap bubble-insulated greenhouse will allow for an extended operating season by increasing the thermal resistance of the greenhouse wall. In turn, this would allow cultivations with longer vegetation periods and also a longer harvesting season.

2.1.4 Waste

Waste prevention, re-use and similar measures could lead to net savings of €600 billion, or 8% of annual turnover, for businesses in the EU [5]. Within the HOUSEFUL project, we will further show that an efficient treatment and valorisation of blackwater and bio-waste could be used as an efficient resource for biogas production.

Blackwater and bio-waste will be treated together with a tailor-made compact AnMBR (Anaerobic Membrane Bioreactor) and dAD (Dry Anaerobic Digestion) reactors. The recovered biogas will be purified on site for storage during winter for further valorisation or used for direct electricity and heat production, reducing building energy needs. Resulting digestate will be treated and made available as fertilizer by the local community. Treated blackwater from AnMBR will be disinfected by UV hygienisation, for reuse.

AnMBR has never been tested and demonstrated for the treatment of wastewater and bio-waste at building scale. In HOUSEFUL, optimal AnMBR configuration and membranes will be selected for efficient treatment of blackwater (↑COD) and grinded BW (↑COD, ↑SS) mixed at optimal ratio at lab scale.

Compact, transportable and modular dAD aims to efficiently valorise bio-waste and manure for biogas production and compost at building scale. The system needs to work in a semi-continuous mode, being able to be automatically fed with almost dry waste. The technology will be designed according to energy needs of the building but also considering energy/compost needs of the neighbourhood which can provide bio-waste for renewable energy production and receive benefits from their engagement (i.e. compost). The system will be offered as a leasing service to promote the circular use and transition from property ownership to functionality (pay per use).

The AnMBR and dAD systems will allow a minimum recovery of over 95% food waste and 95% of organic matter from blackwater and wastewater for production of renewable energy from biogas and compost at home. Furthermore, biogas may be purified for storage

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and then used in winter times according to energy needs of buildings (or surrounding infrastructure in the neighbourhood as part of a potential collaborative economy), for CHP or heat generation and consumption by the own building (2600 kWh/y renewable energy from biogas), or other co-creation possibilities. An exhaustive cleaning of biogas impurities (CO_2, H_2S, dioxins) could allow its valorisation as natural gas-like fuel. Purified biogas can be stored and valorised for the production of renewable energy. HOUSEFUL will define the optimal energy valorisation options to cover energy needs of dwellers.

Several solutions for the stabilisation of bio-waste from anaerobic digestion systems will be tested at semi-pilot scale (laboratory environment) before demonstration and optimisation at building scale once connected to foreseen AnMBR or dAD technologies. In particular, an innovative compost cultivator prototype will be developed and optimised for large scale composting of fresh gardening wastes before mixing it with the dAD digestate.

Finally, an optimal waste management at the end of the building life cycle will allow analysis of maximum recovery and valorisation potential of existing building materials (i.e. envelope, facade, etc) to guarantee the best wastes management (reduction of 30% CDW disposed in landfills).

2.1.5 Energy

Many EU projects have focused on reducing the energy demand and increasing the share of renewables in buildings with the aim to achieve NZEB. New business models are needed to be applied in the housing sector (i.e. pay per performance). HOUSEFUL will design energy efficient facades and roofs considering a circular approach, taking into account modular, prefabricated and off-site construction, design for disassembly, materials reuse, and recycling aspects will be considered.

An energy-saving service will be offered to reduce the non-renewable energy consumption in the usage phase of buildings and reducing billing costs to the lowest level. Energy improvement solutions such as envelope interventions (e.g. innovative facades, energy-efficient windows, etc.), solar thermal systems and shared photovoltaic systems will be proposed to reduce the energy demand of buildings and increase the share of renewable energies, contributing to the attainment of a near-Zero Energy Building (nZEB). The service includes an initial evaluation of the feasibility of proposed energy solutions as well as energy tips for dwellers to reduce energy costs, and the best renewable systems to be implemented, according to building characteristics, end-user profiles and the national regulations and energy markets backgrounds.

HOUSEFUL will guarantee co-creation based on performance rather than ownership, for energy systems (as solar thermal or photovoltaic) finally installed in each building (pay-per-performance business model) and monitoring of energy saving by active and passive measures adopted, from a material and energy valorisation points of view. Pay-per-performance business models will be promoted to be applied in the residential sector, where production is billed rather making the product available for ownership. By using this model, it is guaranteed that solar thermal and photovoltaic systems operate properly at least during the contract duration signed between the energy service company and the owner/neighbourhood community of the building. At the same time, these models proposed for leasing and rent require continuous monitoring of not only of the renewable energy production, but also of the energy consumptions of the end-users. Providing them the related information will help to reach the energy saving goals and thereby ensure the service under the agreed conditions.

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3 EXPECTED HOUSEFUL IMPACT

The HOUSEFUL solutions pursue specific objectives for a more circular housing sector: the design of new efficient processes and procedures for the construction/refurbishment and demolition phases, leading to net reduction in the use of resources, minimising the waste destined to landfills (reduction from current 40% to 10% in 10 years as realistic scenario) and selection/use of sustainable materials to improve the energy efficiency of buildings. The innovative technologies will be offered as new circular services for the production of treated water for internal reuse (i.e. for toilets recharge and irrigation), the generation of renewable energy at residential level of biogas for own consumption (i.e. CHP or heat) and the compost production for garden purposes for yourself and neighbours. In detail, the following technical objectives are foreseen: the recovery of more than 95% of food waste at home level by the successful separation of kitchen waste at source, grinding and valorisation as biogas; the recycling of over 90% of rain-, grey- and blackwater for production of reclaimed water and biogas; high quality biogas production from grinded bio-waste and blackwater and efficient valorisation (over 90% conversion yield) as renewable heat and/or electricity at home level, able to endure the winter with its own heating system; high quality compost production from anaerobic digestate produced from the joint valorisation of bio-waste and blackwater; reducing the non-renewable primary energy consumption of buildings up to 50% related to the national regulations requirement by integrating the existing and proposed passive and active solutions, contributing to the achievement of near-Zero Energy Buildings (NZEB).

From the point of view of economic benefits, HOUSEFUL will provide new opportunities for (social) housing sector by offering new solutions with circularity principles having in mind the reuse of materials, resources and increasing the energy efficiency of buildings by passive and active planning. The uptake of recycled construction materials by other industries boosts industrial symbiosis at local/regional level. A preliminary evaluation of HOUSEFUL solutions predicts cost savings as follows: long-term cost savings of 10% (on average) of external energy and tap water costs through the use of treated wastewater and recovering of energy at building level; 80% (on average) costs saving of using treated wastewater and recovering energy at building level in relation to all external costs (including infrastructure cost); 70% (on average) savings on current fees for the treatment of wastewater and waste management of bio-waste.

From a point of view of social benefits, HOUSEFUL will create different circular economy business models for EU markets for waste, water, energy and material flows and will be designed to promote leasing, customer services and capacity building services. Since the responsibility of the service/product/technology lies with the provider and not with the costumers, the quality of the services is higher and much more in demand [6].

In terms of environmental benefits, HOUSEFUL will tackle the energy efficiency of existing and newly constructed buildings in two different ways: by using a μCHP to provide end-users with heat and electricity from wastewater and bio-waste and by planning and designing the use of more energy efficient products and services in the preventive, corrective and replacement phases of selected residential buildings. With these solutions, we estimate a reduction of up to 60% of CO_2 emissions, contributing to the efforts to limit the global temperature rise to 1.5°C, as provided for in the COP21 Paris Agreement.

The optimal use of the water, bio-waste and materials cycles within the building will reduce by up to 40% waste ending up in landfill, enabling recovery of up to 95% of food waste and the recycling of over 90% of WW (grey- and blackwater) for water reuse (e.g. irrigation, toilets), improving the energy efficiency of buildings of up to 30%. The 40% reduction in waste disposed of landfills will significantly reduce the risk of hazardous

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substance released into the environment (e. bituminous mixtures, solvents, paints) that are strongly harmful to the environment and human health.

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LIVING WITH WATER: A CASE STUDY FOR COASTAL MIXED-USE MULTIFAMILY RESIDENTIAL STRUCTURES

ERIC "BLAKE" JACKSON
Stantec – Buildings Group, USA

ABSTRACT

This examines *The Eddy*, a new construction mixed-use, multifamily residential project in Boston, MA USA as a model for sustainable and resilient urban waterfront redevelopment that celebrates place – rather than evoking fear – while building a sense of community and continuity along the waterfront. *The Eddy* is situated in the neighbourhood of East Boston on low-lying, reclaimed former-industrial land. Because of its place along the waterfront, this building is one of many projects viewed as a linchpin for a unified front against rising sea level, storm surge, and climate change for the entire neighbourhood. This study explores drivers for resiliency on this project, as well as strategies and tools used by the designers, construction team, and municipality leadership in incentivising and directing sustainability and resiliency efforts in a coordinated fashion on this and adjacent properties. Then, the paper explores the project's siting, landscape, architecture, interior design, and mechanical considerations and how each impact greater sustainability and resiliency outcomes. Finally, the paper will share the results of these implemented strategies, including operational cost savings, project marketability, and reduced insurance premiums as a result of the resilient and sustainable design approach, proving synergy and return on investment for implementation of each in tandem. The goal is to illustrate that through cooperation between public and private partnerships, cities can grow and densify intelligently while promoting increased resiliency, sustainability, density, identity, and waterfront access – applicable to any waterfront city.

Keywords: resiliency, sustainability, landscape, regenerative design, housing, multifamily, climate change, urban planning, urban design, architecture.

1 INTRODUCTION

The inexorable drive for increased urban density and our innate desire for close proximity to the waterfront drives development; enriches connectivity to history, nature, and recreation; and provides opportunities for memorable open spaces. However, threats to the built environment posed by climate change and natural disasters (Fig. 1) – so recently tragically revealed by Hurricanes Harvey, Irma and Maria – are a major concern as we move into a less predictable and more dynamic future. What lies ahead for real estate in dense coastal cities as they strive for intelligent growth?

2 A SMART APPROACH ON A VULNERABLE WATERFRONT

Among the most vulnerable North American cities to climate change is Boston, currently undergoing its most rapid growth of its 387-year history [1]. Billions of dollars are being invested into new mixed-use developments and neighbourhoods. Boston's economic vitality, like many growing urban centres, is based on it being a nexus for several industries: finance, education, healthcare, and research. Boston occupies primarily reclaimed land (Fig. 2), linking a collection of former islands and peninsulas, resulting in its current urban morphology. While the city's aged infrastructure and existing building stock are already vulnerable to the previously mentioned challenges, the majority of new development continues to occur within the most vulnerable, low-lying reclaimed areas closest to the coast. While a wonderful problem to see such strong demand from a real estate perspective, it is a long-term challenge to protect these properties from climate change, namely rising sea level.

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180091

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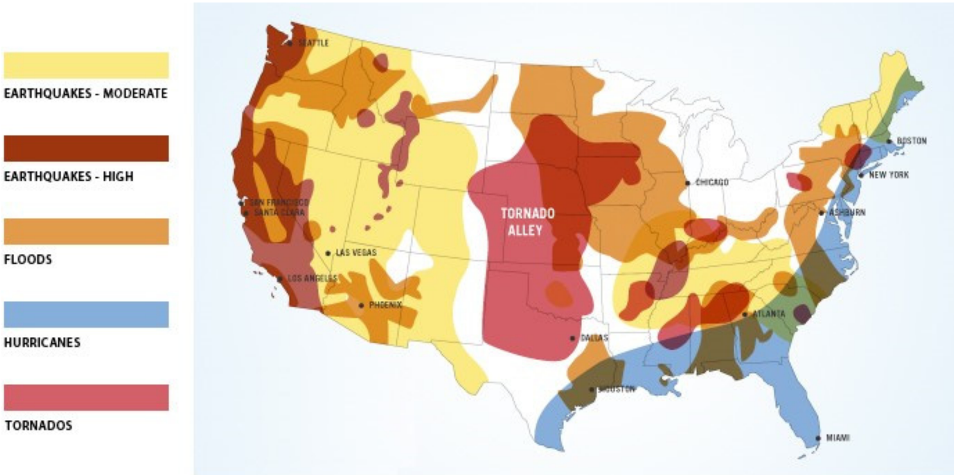

Figure 1: Layering of regional natural disaster risks relative to major North American cities. *(Source: www.alertsystemsgroup.com.)*

Figure 2: Illustration of Boston's historic expansion through largescale land reclamation. *(Source: www.theshawmutproject.org.)*

While this poses stark challenges, developers are learning from previous storms like Hurricanes Sandy and Katrina to formulate cost-effective strategies, which protect built developments and enhance waterfront access, while promoting initial and operational cost savings. A good example of smart development in Boston that is replicable in other coastal cities is *The Eddy*, a 267,500 sf (24,850 m^2), \$104 (£79) million residential mixed-use

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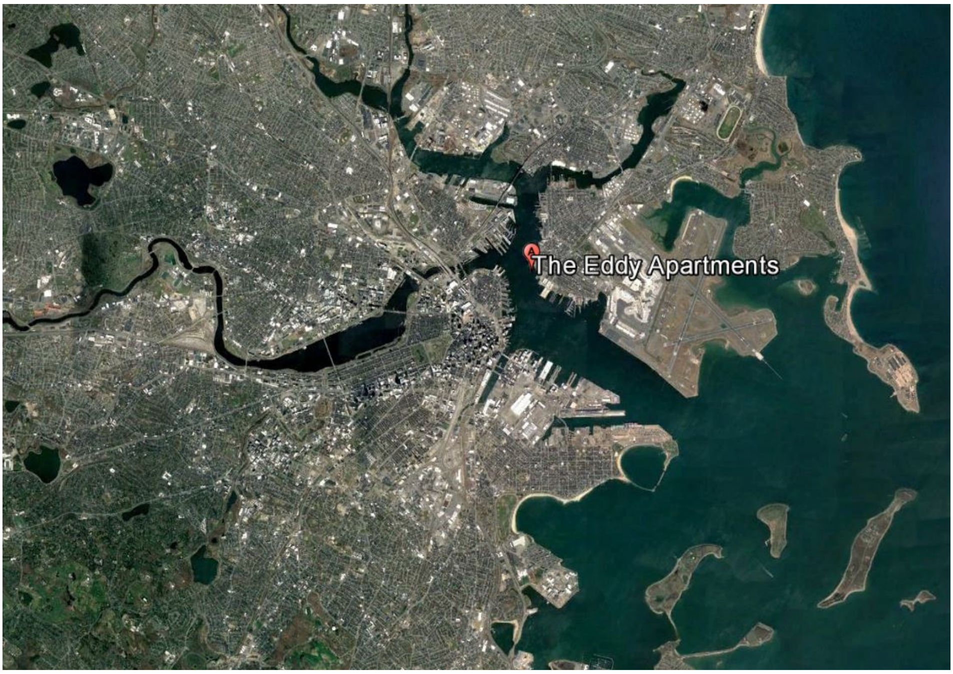

Figure 3: Modern-day Boston illustrating the location of The Eddy within the East Boston neighbourhood, adjacent to the airport. (*Source: www.googleearth.com.*)

development on 4 acres of previously underdeveloped waterfront property in East Boston, one of the lowest-lying, most vulnerable neighbourhoods in the city (Fig. 3). Designed by Stantec, it features 259 apartments, 5,000 sf (465 m^2) of commercial space, parking, and public waterfront parks.

3 MUNICIPAL GUIDANCE

While much credit can be given to an informed client and a capable design and construction team, policy, and municipal planning support, with incentives to guide the development towards doing what was right for its parcel and respective neighbourhood, was crucial. Boston is ahead of other major US cities, having required since 2007 that large developments (> 50,000 sf/4,650 m^2) demonstrate resiliency and sustainability features in order to obtain a building permit. The Boston Planning & Development Agency (BPDA) requires these projects demonstrate LEED Silver compliance and comply to a resiliency checklist, focused on identifying floodplains, water body proximity, site porosity, materials, systems, and their ability to adapt over time to climate change, including increased heat, sea level rise, and precipitation. To aid teams, the BPDA developed the Climate Ready Boston Map Explorer tool (Fig. 4), an online GIS map that visualises these impacts over all individual parcels within the city. Using this free online tool, teams can make informed decisions to guide permit approval and better design outcomes.

In 2017, Boston launched *Imagine Boston 2030*, its first comprehensive masterplan in over 50 years [2] to offer a vision for the future growth and prosperity of the city. Both sustainability and resiliency were key drivers in the masterplan. Anticipating its evolution

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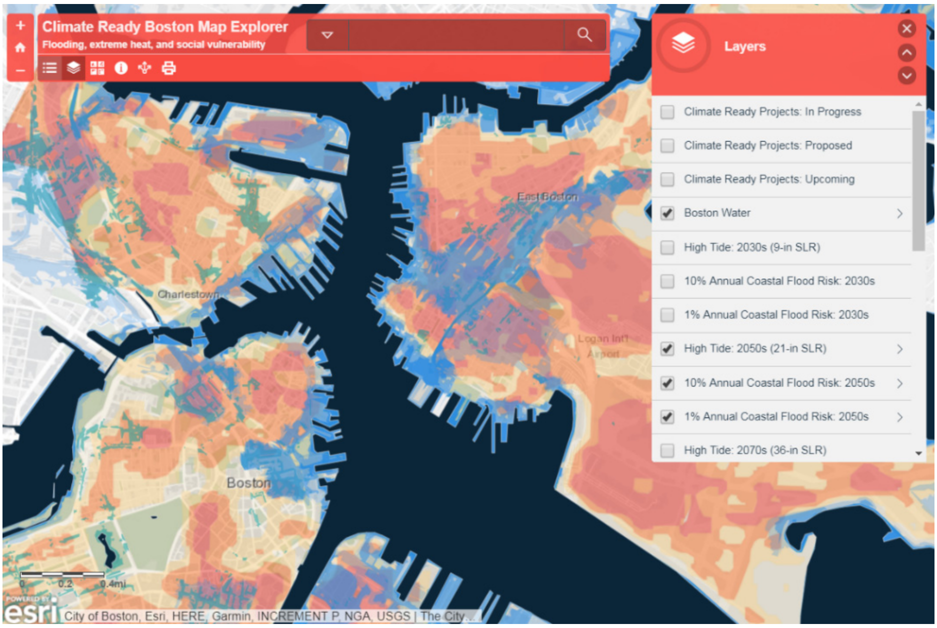

Figure 4: This screenshot illustrates various GIS mapping tools the municipality provides for developers and designers to use to visualise climate change impacts for city parcels. *(Source: www.boston.gov.)*

over time, as private partnerships come onboard, the city is able to apply a long-range view in working with private entities to help them understand how their projects fit into this framework, resulting, over time, in a more resilient city (Figs 5 and 6). *The Eddy*'s site manipulation strategies protect the building and the neighbourhood, while the green spaces surrounding it were developed to connect to local standards already in place, linking existing masterplan elements to encourage continuity and resilience. While the city gained ground implementing its plan, and the neighbourhood gained open, green space and waterfront access, the developer was allowed greater density; thus, the negotiations for sustainability and resiliency resulted in long-term benefits for all parties.

4 FINDING SAVINGS THROUGH RESILIENT DESIGN

Anticipating sea level rise, increased precipitation and heating days, and potential damage due to storm surge, the developer, Gerding Edlen, wanted to build a development that did more than just meet code. Their vision was a property that could rebound within three days after disruption. Article 37 compliance – an ordinance requiring new developments be designed to meet LEED Silver certification – helped bundle what might have been perceived as cost premiums for resiliency into the costs for required LEED compliance. For example, the newly enhanced open, green space helps the project earn LEED points while increasing resilience. Native coastal plantings that thrive in saltwater (even when inundated) are featured, and three-dimensional landscaping serves as a passive barrier to break apart storm surge and funnel water away from the building, protecting it during disruption and beautifying the site during normal operations (Fig. 7). These features, among others, helped the project eventually earn LEED Gold certification.

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Figure 5: Sea level rise without intervention for a 100-year storm event in 2030 (9"/23 cm) and 2070 (36"/66 cm). *(Source: www.boston.gov.)*

Figure 6: Implementation of the Imagine Boston 2030 masterplan shows a unified waterfront through a combination of architecture (*The Eddy* in center), infrastructure, and open space. *(Source: www.boston.gov.)*

Additional savings came from clever site manipulation and space planning. It is common, even in Boston, to place electrical equipment and emergency back-up generators below-grade, despite the high-water table. While saving space, this practice increases expenses because of high waterproofing costs. *The Eddy* features roof-mounted generators (along with

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Figure 7: The enhanced Harbor walk serves to protect the development via enhanced seawall and absorptive green spaces flanking the structure, which channel runoff and reduce storm surge force impacts. *(Source: Stantec Buildings Group.)*

most mechanical equipment, including a cogeneration plant, which saves $150,000 (£113,000) in annual energy costs) with sufficient fuel for four days of power. All electrical equipment is also placed in a protected space at grade elevated above the 500-year floodplain (Fig. 8). Additionally, using onsite fill to elevate grade reduced trucking costs, saving front-end construction costs. Furthermore, to protect from storm surge, the old sea wall was reconstructed to a higher datum point to avoid flooding, which was commonplace before redevelopment. Entrances are reduced along the waterfront side, with the main entry safely faces away from the coast onto an accessible public way. Wet floodproofing techniques allow the ground level to quickly resume normal operations after an event, which also reduces daily maintenance costs through squeegeeing and air-drying [3].

5 RESILIENCY AS A CELEBRATION OF PLACE

These strategies are not a radical departure from code compliant construction; yet, they promote place-based design that discourages fear of waterfront locations. The resulting design creates a harmonious celebration and respect of the historic relationship of human development to waterfront sites through a marriage of "soft" and "hard" infrastructure – landscaping and buildings designed to coexist during normal operations and disruption. Here, a new water taxi connects the neighbourhood to downtown Boston, new fishing stations, and a new signature restaurant along the enhanced Harbor walk, a 43-mile (69km) linear park

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Figure 8: The ground floor elevation was elevated above the 500-year floodplain. At the new high point onsite, the design team located external transformers to save cost and space, provided fire pump access, and provided a secondary means of egress. *(Source: Stantec Buildings Group.)*

along Boston's shoreline, all are for the joy and socialisation of residents and non-residents alike. These strategies illustrate synergies between sustainability and resiliency for long-term operational and maintenance savings, which ultimately also become a branding opportunity (Fig. 9). The developer sees resilient developments achieving top-of-market pricing (2–18% higher for studios and 2-bed apartments), faster leasing, higher renewal, and higher occupancy rates [4]. Additionally, *The Eddy's* entitlement process was expedited due to its compelling resiliency/sustainability narrative. Notably, insurance premiums were also reduced from $10 million to $1 million by the underwriter, Affiliated FM, because of the body of proof of protection from multiple risks, including flooding, wind, and storm surge [5]. This is all a win-win for the developer, the community, and the environment.

6 CONCLUSION

This project provides insight into the process and potentiality for waterfront development anywhere, serving to demonstrate that common sense approaches, collaboration, tools, and incentives can utilise development to champion resiliency, sustainability, and narrate a positive future for waterfront cities. Until cities move the conversation around resiliency beyond fear of loss (the purview of insurance agencies) cities will continue to struggle with balancing growth with uncertainty in an unknown future in respect to climate change impacts. The 2017 hurricane season should have served as a wakeup call for the need for greater urban

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Figure 9: Level 1 view onto the harbour/skyline. *(Source: Stantec Buildings Group.)*

resilience. Developments, like *The Eddy*, create pathways towards a future where climate uncertainty won't be detrimental to the hope of urban vitality within cities. Particularly for our coastal cities, this relationship serves as a major attraction fueling their unprecedented growth, which shows no signs of slowing down.

ACKNOWLEDGEMENTS
The author would like to thank James Gray, Zachary Pursley and Matt Edlen for sharing information regarding the design process and trending economic performance metrics. Additionally, he would also like to thank Maggie Meluzio and Anu Sabherwal for their proofing and formatting support.

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LIGHTWEIGHT RECONFIGURABLE STRUCTURE SYSTEM (LRSS): RETHINKING TEMPORARY BUILDINGS

SHAOXIONG LI & KAIHUAI DENG
School of Architecture, Southeast University, PR China

ABSTRACT
The concept of temporary buildings may have many forms or definitions in different countries and regions. In China, they are defined as buildings and structures that are simply constructed for temporary use of production and life and are required to be demolished within a specified period of time. Container houses are the most common type in China. They have been widely used in post-disaster recovery, temporary resettlement of industrial workers and low-income groups. It also plays an important role in different historical stages. It is undeniable that they have the advantages of simple construction technology, fast construction speed, integration and high degree of modularization in practical application. However, from the beginning of the Wenchuan earthquake in 2008, as well as the subsequent series of natural disasters, their design and functional defects were exposed. Through the spot investigation and questionnaire survey, this paper summarized these issues. For the reason that, this study attempts to fill this gap by introducing a new lightweight reconfigurable structure system (LRSS). First of all, in order to meet the needs of national conditions, the system is based on new modular design and manufacturing methods, quick to build and construction, but also easy to disassemble and transport. Moreover, the new design breaks through the traditional style of component form and size restrictions, with more human and sustainable features. Finally, through computer simulation and analysis, it is convinced that the new products have better comprehensive performance. Multiple comparison results are sufficient to illustrate the new structural system can meet the demand of people whom at different age even different social stratum, and ultimately achieve a win–win results from both social and environment system.
Keywords: lightweight, reconfigurable, structure system, temporary building, modular design, comprehensive performance.

1 INTRODUCTION

Containers are the most representative of temporary buildings and their use in China is very common. For a long time, they were widely used as temporary shelters to help victims of natural disasters and industrial workers involved in large-scale construction. In the past decades, a great deal of work has been carried out by relevant domestic research institutes and administrative units. Its purpose is to improve the comfort level and application scope of the container building. And in 2013, the technical specification for modular freight container building was promulgated. Indeed, compared to canvas tents that people can only use during hard times, container houses have unparalleled advantages in every respect. And it seems that for a long period of time, the use of container buildings as a transitional emergency plan is a global trend [1]. However, we cannot help but ask, is the container house really perfect? For this reason, we chose a temporary container house on a construction site in Nanjing as a research object. On-site inspections and tests were conducted on these container houses, and from our review of various official documents and research papers, some representative problems were integrated to be summarized by four keywords: “safety”, “comfort”, “beautiful” and “suitable” [2]. At the same time, we also grouped these issues into a questionnaire survey to allow actual users of these container houses to score according to their own experience (Fig. 1). Each question was ranked based on the importance of given needs from “not at all important” to “extremely important”. Finally, we received 160 copies of the completed questionnaire, 158 of which were valid.

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180101

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Temporary Container House User Experience Survey

Gender:__________ Length of stay:__________

Education background:__________ Profession distribution:__________

Note: The number of 1 to 5 indicates the degree of importance of needs, rated from "not at all important" to "extremely important"

Number	Attributes	Influence Factors	The Degree of Importance				
			1	2	3	4	5
1	Safety	Restricted height of main structure without auxiliary facilities					
2		Door and window size limited by structure					
3		All structural components exposed					
4	Comfortable	The indoor temperature is uncomfortable in the absence of air conditioning in summer or winter					
5		High humidity in indoor air					
6		Indoor natural lighting and insufficient ventilation					
7	Beautiful	Architectural appearance is too monotonous					
8		Lack of diversity in combination					
9		Neat internal storage space					
10	Suitable	Internal functions cannot match actual needs					
11		Poor sound insulation of container building					
12		The sustainable energy-saving design					

Figure 1: Questionnaire survey.

The vast majority of the respondents lived in a container house for more than three months and less than one year (Fig. 2). The educated information of the respondents is also very consistent with the actual situation, and the occupation distribution is relatively balanced, so it can be said that this statistical survey is extremely representative. After statistically calculating the average score of each sub-item, it can be found that the vast majority of users are most concerned about the comfort of container houses (Fig. 3). In fact, many problems were found in the field investigation. For example, in the autumn of Nanjing, the outdoor temperature at noon is twenty degrees, but when the sun shines directly on the surface of the container, the temperature is close to fifty-six degrees. The final ranking of each individual question also directly corroborates our point of view (Fig. 4). "No air conditioning in summer or winter, the indoor temperature is uncomfortable" is an option that almost everyone feels is in urgent need of improvement, so it's not surprising that it ranks high on the list.

2 INTRODUCTION

Lightweight Reconfigurable Structure System (LRSS) (Fig. 5) is a temporary structure based on the concept of industrial product design. Its standard module is a hexagonal cuboid, and its appearance is similar to that of honeycomb structure. This architectural style inspired by the bionics is not to cater to people's visual curiosity, but to make choices based on practical needs. The basic modules of the LRSS can be either independent temporary buildings or they can be combined with each other to form a complex building group. Like the Lego blocks we have played. If we used to be limited by the contradiction between basic modules and diversified combinations, then LRSS is an exception. It has achieved a balance between the two. In addition, different from the traditional architectural design method, it creatively decomposes the building into a skeleton and infill system. Wood and light steel are the two main materials that constitute the LRSS (Fig. 6). The main load-bearing components are made of wood. The connecting parts used to stabilize the entire system are made of light steel.

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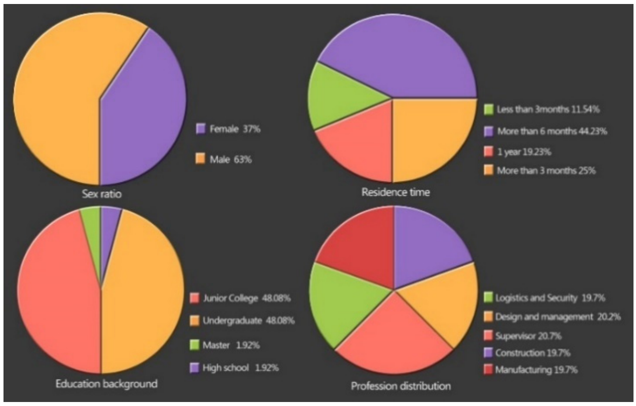

Figure 2: Interviewee information summary.

Figure 3: Score statistics of each sub item.

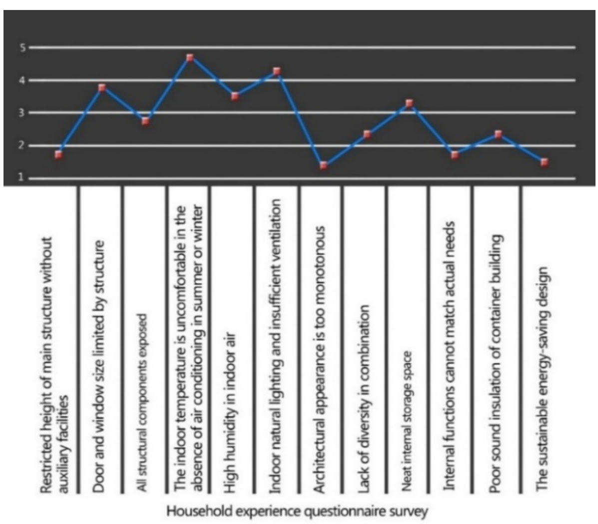

Figure 4: Specific problem score statistics.

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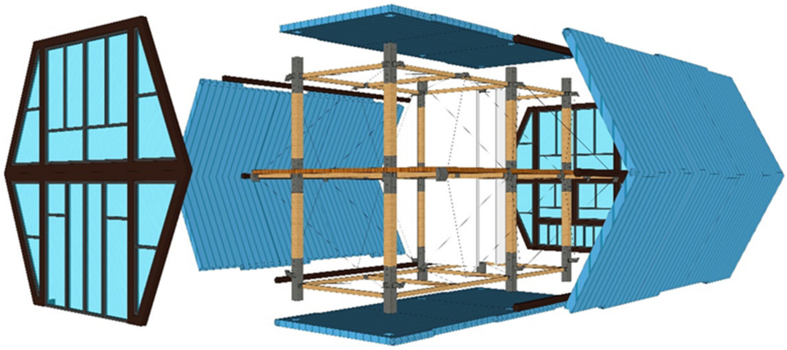

Figure 5: Standard module of LRSS.

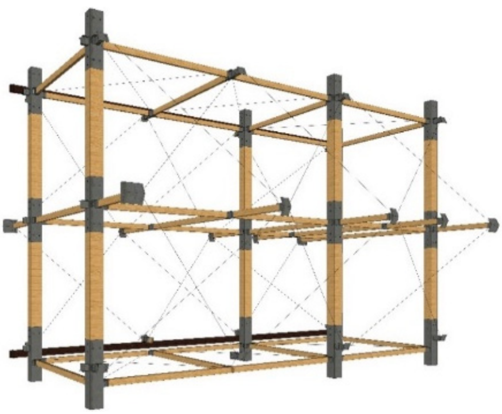

Figure 6: The main structure of LRSS.

Fig. 7 clearly and directly describes the detailed construction method for each connecting node in this new type of temporary building. The two structural columns in the vertical direction are connected by a specially designed light steel component. The connecting part is designed into three segments, the middle section is solid, and the two ends are thin-walled hollow. The column is inserted into the reserved space, and high strength bolts are installed in the reserved holes to achieve the purpose of connecting to each other. At the junction between the outer baffles, there is a connector shaped like an arrow, holding it like a palm. In order to maintain the structural stability to the maximum extent, a long tube is inserted in the horizontal direction at each corner of the hexagon, and the outside baffles are connected in series. Whether it is a roof partition or a middle floor partition, there is a corresponding beam below it as a support member. In the four corners, a specific sheet of metal is used to fix the beams and partitions, while the diagonals are reinforced with slender cables. The splicing method of the entire system draws on the techniques of traditional Chinese wooden architecture. The bolts or mortise-and-tenon joints structure are used among the parts, and the plate are connected by the way of tongue and groove joint. All efforts in this study are aimed at ensuring the firmness and durability of the system as well as maximizing the balance between feasibility and ease of use.

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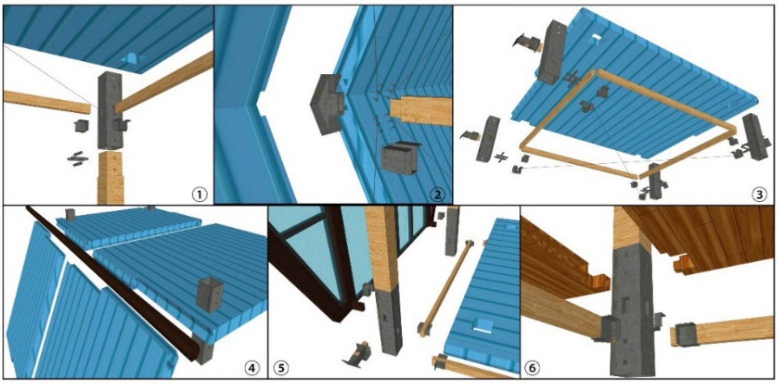

Figure 7: LRSS construction details.

3 METHODS AND DATA

This study includes both traditional design strategies, comparative analysis and performance simulation. The foregoing has described a series of shortcomings in the actual application of existing container houses. Based on China's social and economic conditions, this study needs to be more intuitive to explain the feasibility of promoting LRSS as a temporary building. Since it is a new product, it is necessary to meet the actual needs of the people.

3.1 Net size

Table 1 shows the outer and inner dimensions of the two most commonly used containers. Due to the fact that numbers can't really make people feel the building space, this study draws the standard layout of two container buildings. As can be seen from Fig. 8, because of size constraints, it is difficult for containers of type ICC to form a fully functional dwelling unit and narrow inner channel affects the real experience of the resident. In addition, no matter which type of container, in such a compact space cannot be arranged reasonable storage space. The vertical section of the LRSS is hexagonal with a net width of 3100 mm at the bottom edge and a horizontal distance of 6400 mm between the two furthest corners in the middle and a vertical height of 4800 mm (Fig. 9). In the direction of the long axis, the bottom layer consists of an 8300 mm indoor space (intermediate layer is reduced to 6600 mm) and an outdoor platform of 3300 mm (1800 mm on the outermost side of the platform is removable).

This design can be seen as the optimization and integration of an IAA container in three dimensions. The aim is to reduce unnecessary walking distance as much as possible without

Table 1: Size of two general types of containers [3].

Model	External size			Internal size			Rated quality(kg)
	Height (mm)	Width (mm)	Length (mm)	Height (mm)	Width (mm)	Length (mm)	
ICC	2591	2438	6058	2393	2352	5898	2180
IAA	2591	2438	12192	2393	2352	12032	3640

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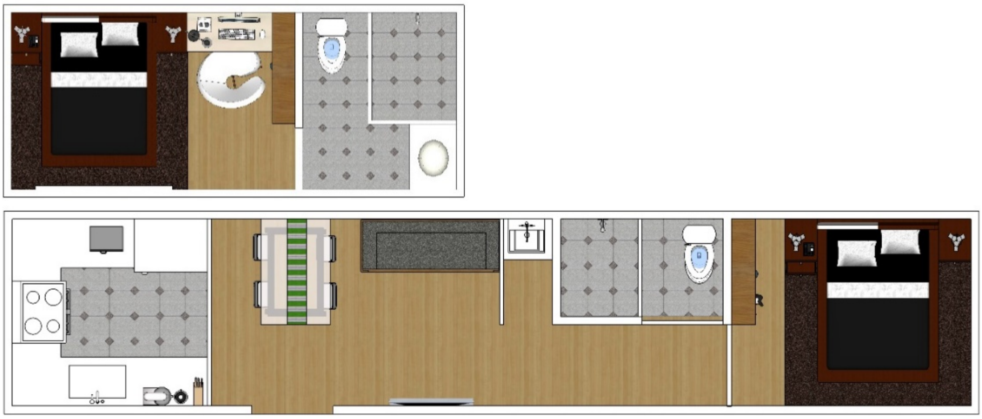

Figure 8: Standard layout of two container buildings.

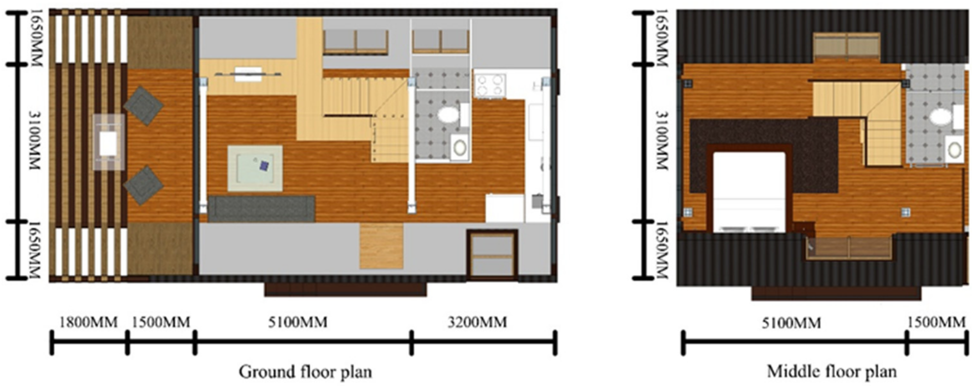

Figure 9: Standard layout of LRSS.

giving up any functional space. In particular, it is possible to avoid the appearance of a narrow corridor connecting all functional spaces, which is very affecting user experience. In addition, a more reasonable functional configuration is achieved when the overall size does not increase significantly. The most significant is that there is an extra terrace for people to relax on the ground floor platform, and a bathroom close to the bedroom (Fig. 10).

3.2 Comfort degree

The body sense comfort should be considered as an important index of a kind of building. Unfortunately, When policymakers and investors see low-cost container buildings, everything seems to be less important. In order to get the most intuitive conclusion, this study takes the layout of IAA containers as an example to conduct a computer simulation of internal ventilation. In this experiment, according to the difference of wind direction, we simulated the ventilation in the container house respectively (Figs 11 and 12).

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Figure 10: Three-dimension effect graph of LRSS.

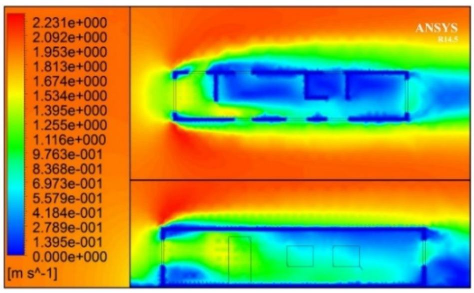

Figure 11: Horizontal ventilation simulation.

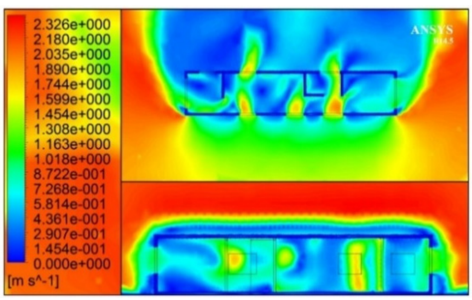

Figure 12: Vertical ventilation simulation.

As shown in Fig. 11, the airflow in the horizontal direction is limited by the size of the container side structure, and the air is easily blocked by the interior wall so that it cannot provide enough fresh air for the room. Therefore, most functional spaces cannot feel comfortable with natural ventilation. Even though the corridor space runs through the room, the air flow also shows significant attenuation as the distance increases. The long side of the container has enough space to enlarge its window-to-wall ratio. So as shown in Fig. 12 the indoor ventilation has improved significantly when the dominant air flow comes from the vertical direction. Especially when there are corresponding windows in the same position on

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both sides, there will be obvious air convection effect. It remains to be said that the so-called "equilibrium" problem we have been emphasizing has not been properly addressed. It can be clearly seen that the ventilation effect in the bedroom and living room still needs to be improved.

Through computer simulation, we can most intuitively see the indoor wind environment of LRSS. And in order to make the simulation results more persuasive, the parameters and boundary conditions set in this simulation are consistent with the previous container simulation. Compared with traditional container houses, the position of windows in the LRSS is more reasonable, so it can be clearly seen from Fig. 13 that there is a significant convective wind effect in the interior of the LRSS. Fig. 14 shows that the air flow entering from the vertical direction can easily penetrate the entire space.

3.3 Operating energy consumption

product that meets the needs of the current people, is bound to conform to the characteristics of this era. In order to make the subsequent energy-saving measures and design strategies more detailed and effective, this study separately conducted computer analysis of the energy consumption of the IAA container house and the LRSS. The simulation results of two different types of temporary buildings are derived from a software called EnergyPlus (version

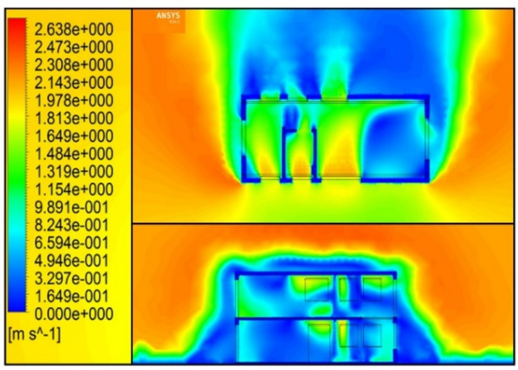

Figure 13: LRSS horizontal ventilation simulation.

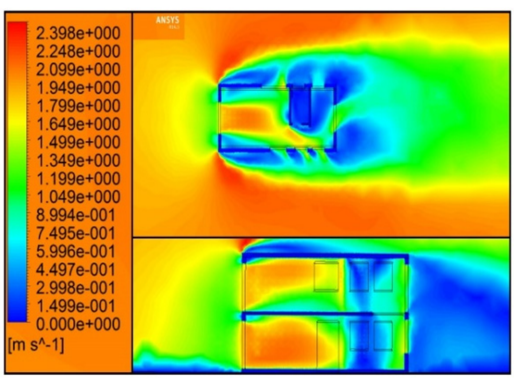

Figure 14: LRSS: vertical ventilation simulation.

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8.8). The two simulation setup has the same external boundary conditions to highlight the difference in thermal performance between different materials. Fig. 15 shows the annual energy consumption results of the two buildings when we set the indoor temperature at 25 degrees centigrade, the same number of residents, the same climate zone, and the same electrical equipment. The results show that in the nearly 2/3 months of the year, the operating energy consumption of LRSS is much lower than that of traditional ones, and the gap between them is significant. The main reason for this situation is that the building materials used in the original system have been overemphasizing lightness and neglecting thermal performance for a long time.

Today, energy saving and environmental protection has become a hot topic. LRSS, as aIn response to this phenomenon, this study combined with the LRSS's own characteristics has innovatively designed the specific structure of the enclosure sheet and matched the corresponding materials. The building envelope of LRSS is constructed in the form of "sandwich". The outermost side of this lightweight composite wallboard consists of two pieces of larch structural plywood. The middle cavity is filled with two pieces of polyurethane foam. Polyurethane foams are connected by GFRP keels and also come with an air gap (Fig. 16). GFRP is a new type of building material. It has excellent material properties

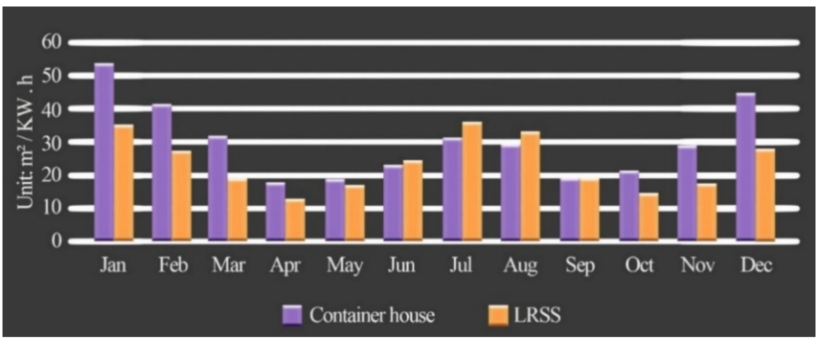

Figure 15: Simulation of operation energy consumption.

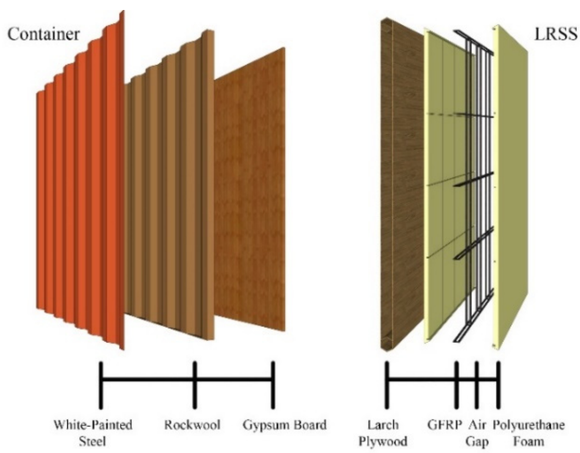

Figure 16: Material composition of envelope.

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such as light weight and strong anti-deformation ability, also provides a variety of options for LRSS modeling and lapping.

As mentioned earlier, the thermal performance of materials affects the overall energy performance of the building. The materials used by LRSS have good physical properties compared with the traditional ones (Table 2). However, it should be noted that LRSS has higher energy consumption in summer. After in-depth analysis, we found that the causes of this consequence are two aspects. First, the two side facades of the LRSS are made of glass, and when the summer comes, there will be a lower thermal insulation performance. Second, overemphasizing the simplicity of the overall design and neglecting the design of effective shading members. All the defects found in this research will be solved in the following "prototype improvement" research.

3.4 Transport and construction

As time goes by, the cruel lessons in practical use tell us that there is still a huge gap between expectations and reality. In 2013, School of Architecture of Southeast University participated in the first solar decathlon competition held in China. The Solar Decathlon is an international competition among universities created by the U.S. Department of Energy and related to high-performance residential-related research [8]. Taking into account many factors, they chose to use three IAA containers as the main framework. Because it is necessary to comply with the relevant regulations of China's highway transportation safety regulations, the 12-meter-long IAA container consumes a lot of money and time in the transportation process. Furthermore, due to the temporarily dispatched for on-site construction, they are still not completed on time [9]. Not only that, but also based on the preconditions for ensuring the safe use of container houses, relevant regulations have made corresponding restrictions on the side window opening dimensions and building height of the container according to the structural characteristics of the container itself. The staircase in the picture seems to be only a function of vertical traffic, but its larger role is to resist the possible lateral thrust for the main structure as shown in Fig. 17.

At the beginning of its design, LRSS took into account the subsequent transport and construction problems. The core of its design concept is to divide the LRSS into independent functional modules so that the LRSS can be quickly delivered to the destination with only small vehicles. All the parts are custom-manufactured by the factory, and only a few workers and equipment are needed at the site to quickly assemble a fully functional unit. The only

Table 2: Material's physical property parameters [4]–[7].

<table>
<tr><th colspan="3">Material thermal conductivity of IAA type container</th><th colspan="3">Material thermal conductivity of light reconfigurable structure system</th></tr>
<tr><th>Material</th><th>Thickness</th><th>Thermal conductivity</th><th>Material</th><th>Thickness</th><th>Thermal conductivity</th></tr>
<tr><td>Steel</td><td>2 mm</td><td>58.2 (W/mK)</td><td>Larch plywood</td><td>10 mm</td><td>0.16 (W/mK)</td></tr>
<tr><td>Rock wool</td><td>8 mm</td><td>0.045(W/mK)</td><td>GFRP</td><td>10 mm</td><td>0.35 (W/mK)</td></tr>
<tr><td rowspan="2">Gypsum board</td><td rowspan="2">10 mm</td><td rowspan="2">0.33(W/mK)</td><td>Air gap</td><td>10 mm</td><td>0.023 (W/mK)</td></tr>
<tr><td>Polyurethane foam</td><td>40 mm</td><td>0.033 (W/mK)</td></tr>
</table>

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Figure 17: Combination form of container house.

Figure 18: LRSS combination form.

organization principle of functional modules is adaptive adjustment based on different customer needs and different usage environments. As shown in Fig. 18 LRSS fully demonstrates the diversity of its construction form. More specifically, LRSS itself can be used as a structural stress system without the need to build additional support platforms.

4 RESULTS

In summary, due to a series of obstacles such as its internal dimensions, thermal comfort, and structural strength, it is difficult for container buildings to adapt to the requirements of people in the new era. The LRSS in this study is a brand-new product with targeted optimization and upgrading. And based on sustainable design principles, each component designed in LRSS has a set number of reusable times. This will greatly reduce the risk of damage to various components and greatly reduce unnecessary waste of resources. Taking into account the growing maturity of solar photovoltaic integrated products in the future, the special shape of LRSS is to leave room for future transformation. So in areas with high solar radiation, LRSS can not only achieve its own net zero-energy operation, but also have a greater chance of providing energy for the municipal grid. Of course, it is undeniable that as a prototype of new products, we find that there is room for improvement. For example, the problem of excessive energy consumption in the summer LRSS mentioned above. In subsequent studies, we will design targeted sunshade components and optimize window wall ratio.

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5 CONCLUSION

Based on the above discussion, LRSS as a temporary housing module with the concept of industrial products has its advantages. Its appearance will lead to more extensive and in-depth discussions on temporary housing. People began to realize that temporary buildings are still as comfortable, beautiful and durable as ordinary houses. More importantly, it serves as a new exploration path, providing practical and effective lessons for subsequent research, and ultimately becomes the reference for the state to issue relevant regulations.

ACKNOWLEDGMENTS

The research presented in this paper was supported by "the Fundamental Research Funds for the Central Universities" and Postgraduate Research and Practice Innovation Program of Jiangsu Province (KYCX17_0109).

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INNOVATIVE APPROACH TO SUSTAINABLE MATERIAL SOURCING AND ITS IMPACT ON BUILDING PERFORMANCE

JAIDEEP SINGH RAJPUROHIT, BORIS CERANIC & DEREK LATHAM
Department of Architecture and Civil Engineering, University of Derby, UK

ABSTRACT
In this paper, a novel use of building materials and their impact on the building performance and its climatic adaptability is explored, based on a complex case study of a unique low energy sustainable building project. In particular, an innovative use of sycamore and its suitability as a structural and constructional timber has been investigated and reported, given that the current codes of practice deem that is not appropriate for structural applications due to its durability. A research method of in-situ longitudinal study has been adopted, concentrating on the monitoring and assessment of its structural performance and conditions in which it might deteriorate. On the component level, the research reports on the methods and standards of sycamore grading and classification, service classes, resistance to decay, impact of the moisture movement and results of its laboratory and in situ testing. On the system level, the climatic adaptability of the building as a whole has been analysed via dynamic performance simulation and compared to the in situ measurements. This was important in order to develop a holistic building performance monitoring strategy, but in particular, to understand the impact of building microclimate on the sycamore frame and hempcrete components of the external load-bearing wall. So far research has concluded that sycamore can be used as structural and constructional material in building design, but due attention has to be paid to construction detailing and provision of a breathable, low humidity environment with an effective resistance to decay and insect attack. This includes measures that ensure a low equilibrium moisture content conditions, effective ventilation provision and appropriate service class uses. It is important to state however, given the single site locality of sycamore sourcing, that results can only be interpreted in the context of the given case study, i.e. they cannot be extrapolated to broader geographical extents.
Keywords: sycamore,; sustainable design, materials, climatic adaptability, building performance.

1 INTRODUCTION

Sycamore, scientifically known as Acer Pseudoplanatus, is a hardwood tree native to Central Europe and Western Asia and belongs to deciduous tree family. With broad leaved, invasive and resilient in its growth, it is capable of germination under almost any conditions. As stated by [1], it has a low ecological count (less than 25) and supports a small variety of insect life, birds and little other wildlife. Hence, its planned and regular harvesting could not only create an additional source of sustainable timber supply but also generate space for other species to grow, improving the biodiversity of woodlands.

Today, sycamore can be found in 3,461 (89.7%) hectads in Britain, more than any native tree species [2], [3]. Widely available and used among conventional applications like interior joinery, furniture, parquetry and musical instrument making [4], it is not deemed suitable in the construction industry as a structural material due to its perishability and susceptibility to rot and decay, hence could be considered a new paradigm.

Therefore, this research poses challenge to the key principles of sustainable design, raising question why materials which are available locally and in abundance, such as sycamore, are not used more readily, particularly when the majority of structural timber supply in the UK is imported currently from other European countries [4].

www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180111

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Although the research on physical and mechanical properties of sycamore as a material have been investigated and reported in the literature [5], none has tested it as the structural material in real building conditions nor monitored its structural integrity in varied moisture conditions over the long period of the time (a longitudinal performance monitoring of at least five years in the Hieron's Wood research project is proposed). Thus, the proposed performance monitoring strategy includes regular testing of its moisture content, condition and integrity of the sycamore structural frame, including measuring the temperature and relative humidity of its immediate environment [6].

2 CASE STUDY: ENERGY PLUS HOUSE, HEIRON'S WOOD

2.1 Research methodology

The reasoning behind selection of a case study based approach in this research was based on the need to examine performance monitoring through the prism of a complex real word project. The strengths behind choosing case study approach as a valid research method are summarised by [7], stating that it is particularly suitable for analysis of all the complexities and uniqueness of a given project from multiple perspectives, and in real life context. It is considered research based, inclusive of different methods and is evidence-led.

The primary purpose is to generate in depth understanding of a specific topic. According to [8], "the holistic design approach is beneficial when the theory pertinent to the case study itself is of a holistic nature or where no logical sub-units can be identified". However, he further asserts the importance of access to the real world data stating that otherwise the case study may be "an overly abstract, with a lack of suitably clear measures or data".

This research examines sycamore as a novel and sustainable structural material alternative, in the context of the building performance of a single case study and in combination with other materials and integrated passive design strategies. It is triangulated via laboratory experimentation, longitudinal in-situ building performance measurements and building performance simulation analysis.

2.2 Case study

Located on the edge of Little Eaton in Derbyshire, Heiron's Wood is an experimental 4-bedroom house. It is located on a former stone quarry in the vicinity of an existing 1920's house (see Fig. 1(a), (b)). The design intent was to propose a dwelling with a minimal carbon imprint and visual impact on the landscape of the site, considering its historical and physical context and aided by a locally sourced materials to blend building within its surroundings.

The project represents a distinctive opportunity to undertake long term research in monitoring of building performance with respect to: a) energy consumption/embodied carbons/health and wellbeing; b) innovative use of materials and technology; and c) detail design and construction.

To ensure maximum impact of the heat gains from the warm air as it rises, design is based on an "upside down" plan, with sleeping quarters on the lower ground floor and living areas on the upper ground floor (see Fig. 2(a), (b)):

- The lower ground floor consists of an en-suite master bedroom, two-guest room and a study with utility and garden store, with external excess.
- The upper ground floor has an open living/dining/kitchen, larder, WC and an entrance hall.
- The mezzanine level comprises of an open study balcony, looking down to the living and dining area.

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Figure 1: (a) Aerial view of the site location; and (b) Site build progress.

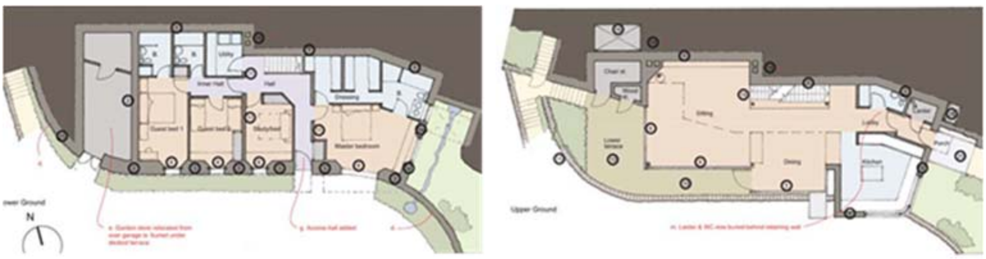

Figure 2: (a) Lower ground floor; and (b) Upper ground floor.

A key principle of an adopted "fabric first" approach was to maximise the performance of the materials and components that make up the building fabric itself, and in doing so create a building that minimises the need for energy consumption in the first place, rather than relying on the mechanical and electrical building services supplies. A number of key design methods were used to achieve this, such as super insulation and airtightness, zoning (see Fig. 2(a), (b)), effective natural ventilation, passive stack and purge ventilation, earth embankment at the northern side, high thermal mass (see Fig. 3(a)), and earth tube as a passive earth to air heat exchange device (see Fig. 3(b)). In addition, the southern orientation of the building maximises its winter solar gains and helps it to capitalise on the PV energy generation (see Fig. 3(b)). Calculations from early energy design simulations show that the building produces more energy through the renewables than it consumes, making it defacto an "energy plus" house.

Figs 4 and 5 below show completed project at the time of client handover.

3 RESULTS AND DISCUSSION

3.1 Structural use of sycamore

When deployed in the service classes 1 and 2 (see Fig. 6(a), it is important to maintain timber at less than 20% moisture content as it is likely to perish due to being attacked by wood decaying fungi or sapstain [9]. According to [10] sycamore belongs to class 5 (see Fig. 6(b)), i.e. it is classified as non-durable and perishable in less than five years.

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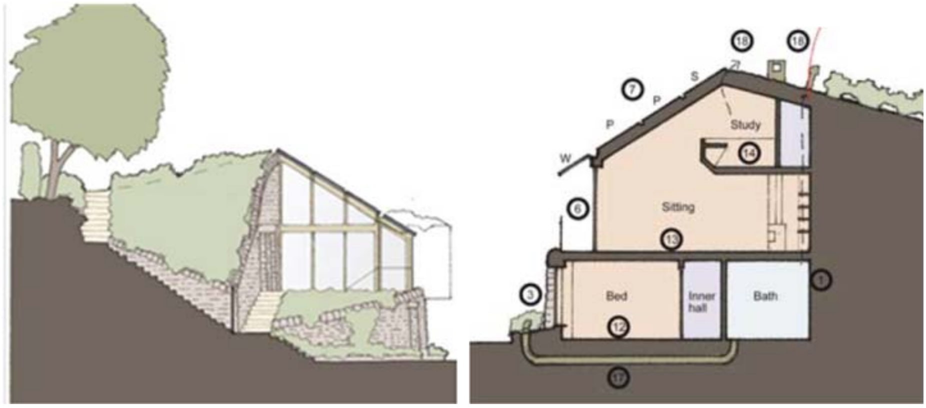

Figure 3: (a) West elevation; and (b) Cross section with southern roof orientation.

Figure 4: South elevation.

Figure 5: South west view from the living room.

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Service Class	Examples of use in building	Typical upper moisture content in service
1	Warm roofs Intermediate floors Timber-frame walls, internal and party walls	12%
2	Cold roofs Ground floors Timber-frame walls, external walls External uses protected from direct wetting	20%
3	External uses, fully exposed	>20%

BS EN 350 Durability classes		BRE classes	
Class	Description	Description	Approx life of 50×50mm stakes in ground
1	Very durable	Very durable	More than 25 years
2	Durable	Durable	15 - 25 years
3	Moderately durable	Moderately durable	10 - 15 years
4	Slightly durable	Non durable	5 - 10 years
5	Not durable	Perishable	Less than 5 years

Figure 6: (a) Service classes and moisture content; and (b) BS EN 350 Durability classes.

However, this BS EN 350 classification is based on the approximate life of 50x50mm stakes driven into the ground, and as this study argues conducted in conditions much more harsh than is probable within the building envelope.

Thus, the research strategy of using structural sycamore in service classes 1 and 2 is proposed, reinforced with the use of appropriate construction detailing, breathable constructions and quality workmanship as the first line of defence and the use of non-toxic preservatives as the second.

Even though the hardwoods are visually graded in practice [11], it was decided to examine its mechanical structural properties as per [12]; specifically it's bending and compression strength, local modulus of elasticity, as well as recording the density and moisture content of each sample samples. The initial results were similar to the published figures (see Figs 7 and 8), e.g. TRADA reports on sycamore bending strength to be 99 N/mm^2, modulus of elasticity 9400 N/mm^2, density 630 kg/m^3 and compression parallel to grain 48 N/mm^2 [13]. These mechanical properties are similar to other hardwoods, reinforcing the notion that it could be used structurally.

Table IV. Compression Test Results

Sample 50x50x300 (mm)	Density (kg/m^3)	Moisture Content (%)	Compression strength II to grain (N/mm^2)
1	566.8	14%	33.1
2	572.3	14%	37.3
3	582.8	14%	38.6
4	585.9	14%	41.3
5	591.2	14%	42.1
6	587.4	14%	39.9
7	580.3	14%	38.8
8	577.4	14%	37.9
9	590.2	14%	41.3
10	578.6	14%	38.4
Avg	**581.3**	**14%**	**38.9**
SD	7.8	0.00	2.6

Figure 7: Compressive strength test.

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Table V. Bending Strength Test Results

Sample 50x50x1000 (mm)	Density (kg/m^3)	Moisture Content (%)	Local Modulus of Elasticity (N/mm^2)	Bending Strength II to grain (N/mm^2)
1	566.8	14%	9785	123.7
2	582.8	14%	9677	96.9
3	571.2	14%	9406	96.7
4	575.6	14%	9529	108.6
5	583.9	14%	9590	91.5
6	575.2	14%	9350	92.6
7	578.3	14%	9370	93.7
8	585.5	14%	9610	97.5
9	579.1	14%	9512	98.6
10	580.2	14%	9570	99.2
Avg	**577.9**	**14%**	**9540**	**99.9**
SD	5.8	0	137.8	9.6

Figure 8: Bending strength test.

3.2 Material performance monitoring strategy

A long term building performance monitoring strategy (at least five years) of the Hieron's Wood development is proposed (see Fig. 9). It consists of the systematic analysis of the sycamore structural frame on both the component and whole system level. The hempcrete that surrounds sycamore I the external wall is monitored with regards to its moisture content, temperature and relative humidity.

The proposed strategy is supported by the research undertaken on the constructing and testing an experimental built at Hill Holt Wood, Lincoln (see Section 3.3). The wireless monitoring on the site is performed via Ethernet manager and sensors.

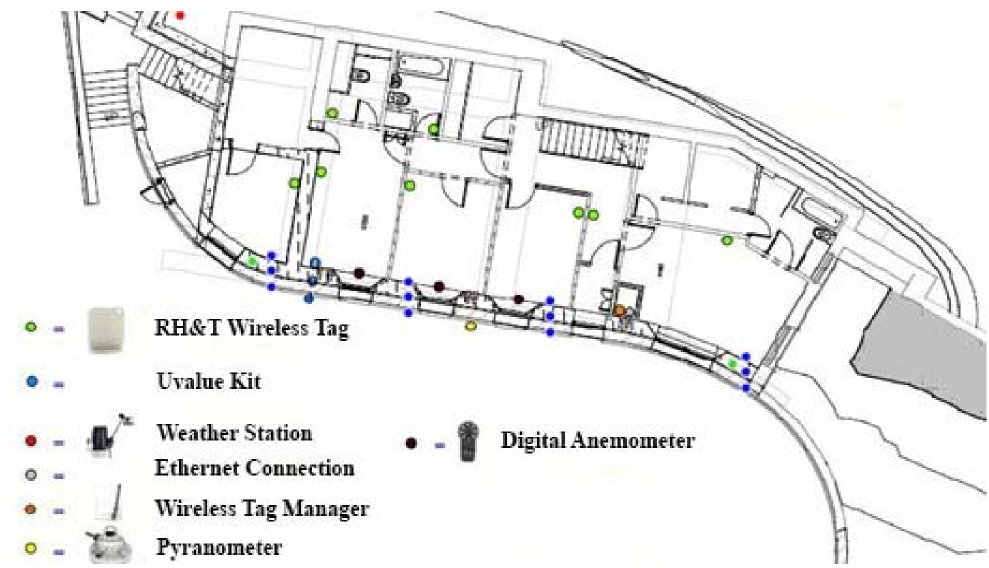

Figure 9: Building performance monitoring strategy: lower ground floor.

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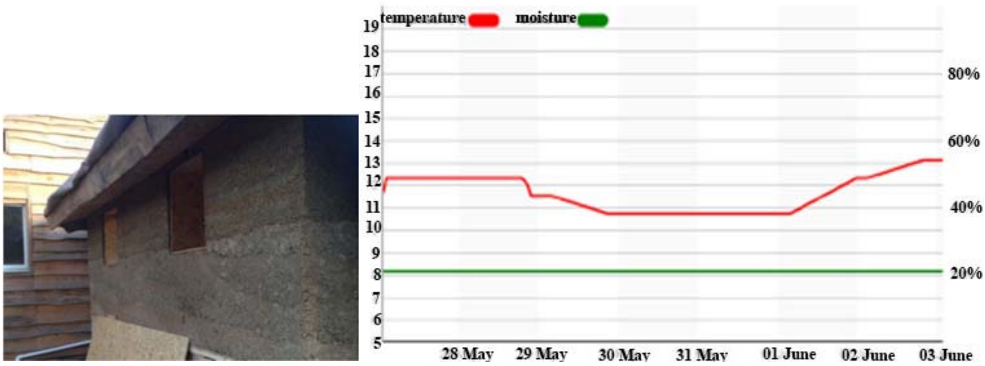

Figure 10: (a) OSB board struck off at the exterior face of the wall; and (b) Temperature and moisture content reading of NW sycamore corner post, 28 May–3 June 2015.

3.3 Experiment build findings

The experimental build at Hill Holt Wood, Lincoln was undertaken to evaluate proposed external wall performance behavior, prior to the actual build. It was a small scale timber building with half sycamore and half softwood structural timber frame, and hempcrete infill, forming an external wall with a total thickness of 450mm. The initial shuttering was with formed with a non-breathable OSB (Orientated Strand Board). The board was struck off from the exterior after the hempcrete has set. It was then rendered with the lime render, keeping the OSB on the interior intact (see Fig. 10(a)).

The temperature and relative humidity sensors installed produced higher moisture readings in the NW corner post, for prolonged periods of time (see Fig. 10(b)). The sycamore was constantly showing moisture content of 20%, even after initial drying of the hemp has taken place. It was observed that the OSB shuttering kept on inside was restricting free moisture movements throughout the wall, resulting in a higher moisture content of the hemp for longer periods, and thus of sycamore too. It was concluded that an envelope has to maintain full breathability and allow for a free and unobstructed moisture movement. Thus the final construction of the external wall for the actual build was fully breathable and composed of, from the outside in, 150mm dry stone walling (with a partial bed of lime mortar for stability, but with random air gaps), 10mm air gap, 450mm hempcrete infill with 150x100mm sycamore frame and lime render on the inside [6], providing uninterrupted moisture movement.

3.4 External wall hygrothermal monitoring

As the hempcrete surrounding sycamore goes through its intermittent periods of wetting and drying, thus changing its moisture content [6], hygrothermal tests were conducted according to ISO 9869 and ASTM C1046 standards specified in [14], [15], recording heat flux and dynamic changes of U-values, to evaluates the building envelope performance and its impact on the sycamore frame. To signify those results, a building envelope performance monitoring of the guest bedroom south facing wall is presented below, covering 3 weeks of typical heating period from 20/02/18–12/03/18 (see Fig. 11).

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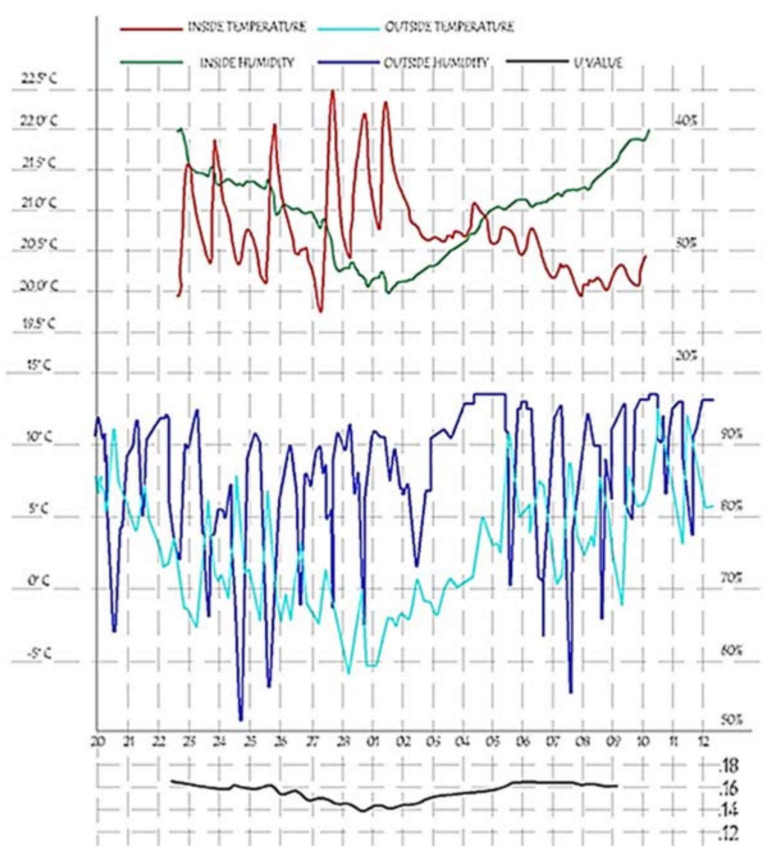

Figure 11: Monitoring results of the guest bedroom south facing wall (20/02/18–11/03/18).

The indoor air temperature was maintained around 20°C to 22°C with the heating, whilst the outdoor air temperature during this period varied between −5°C and 12°C. The indoor relative humidity varied between 27% to 40%, whereas outdoor relative humidity varied between 50% to 95%. The overall average U-value for the analysed time was around 0.16 W/m2K. It was concluded that the changes in the U-value depend on the variation in relative humidity, especially indoor, deteriorating when the hempcrete is in the wetter state and improving when it is in a comparatively dryer state (see Fig. 11).

3.5 Sycamore moisture content monitoring

There was a noticable variation in the moisture content of different structural sycamore members depending on their location, for example master bedroom stud (varying between 11% and 21%) and GF plant room stud (varying between 9% and 15%), albeit both being located within the external wall envelope (see Fig. 12). The readings of the first floor colums situated in the indoor heated environment on the other hand vary a lot less, between 6% and 10%. These results indicate the direct correlation between sycamore's service conditions and its moisture content. The timber that sits in the external wall (service class 2) shows higher readings and the range. This is due to the continous wetting and drying of hempcrete which

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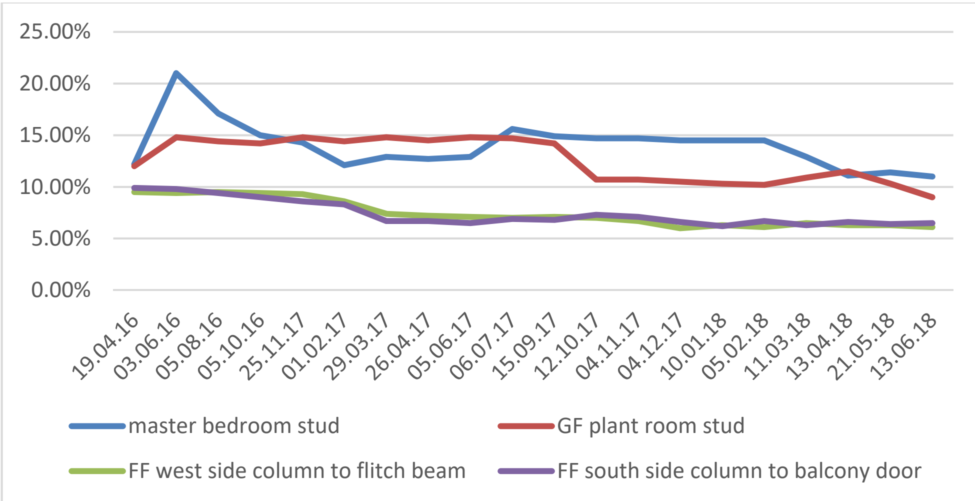

Figure 12: Moisture content readings for sycamore structural members at different locations.

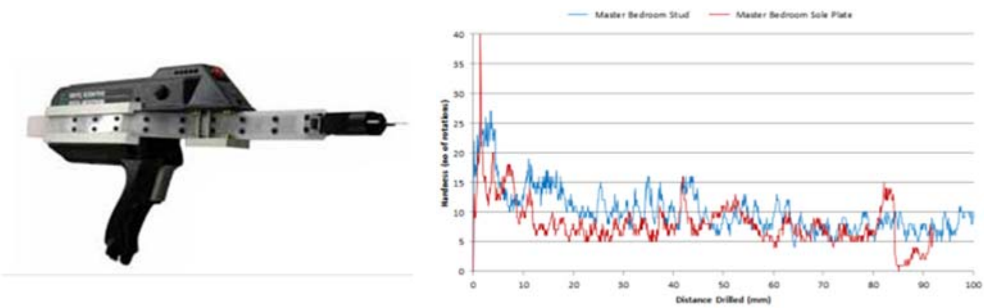

Figure 13: (a) Digital microprobe; and (b) Master bedroom stud and sole plate hardness.

envelopes the sycamore in the external wall. The sycamore on the first floor is situated within the internally controlled environment throughout the year (service class 1) and thus protected from the exposure to changing environmental conditions.

3.6 Sycamore "hardness" and rate of decay

To measure sycamore hardness and rate of decay, especially at the "weak" spots such as the junctions between the sole plate and vertical members, a digital microprobe (DmP) was used (see Fig. 13(a)). DmP is used to detect and analyse wood decay by recording the number of rotations required for its needle to make penetration every 0.1 mm. As the fine rapidly rotating probe penetrates the wood, the rate of progress is measured to determine the condition of the wood. Fig. 13 above shows the *hardness* of the master bedroom stud and sole plate junction. Whilst there are no abrupt decreases in the penetration resistance between the stud and base plate, the latter has some soft wood between 10 and 30mm depth, with a potential cavity discovered between 80 and 90 mm.

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4 WHOLE BUILDING SIMULATION AND PERFORMANCE MONITORING

A building energy model produced at the feasibility stage of the project provided an early understanding of energy consumption and costs, water usage, renewables and carbon neutrality potential. 11 scenarios of heating demand were analysed based on calculations performed for air to water aroTHERM 8kW heat pump (©Vaillant) [9], results of which are listed in Tables 1 and 2. They show that if heat pump flow temperature is kept at 35° and energy efficient lighting and appliances are specified throughout the property, then given its constant predicted PV generation capability, the scenarios 5, 6, 7, 8, 9 and 10 become both "energy positive" and "carbon negative".

In the final stage of analysis, a whole building thermal simulation was performed using IES© <VE> software. Final thermal performance calculations were generated, followed by redesigning of the thermal zones according to these results; hence finalising the design for building control approval and commencement of the works on the site. Fig. 14 below shows the actual and notional energy summary, compliant with the Building Regulations Approved Document L document. The actual building emission rate was estimated at 10.25 $kg.CO_2/m^2.yr$ which is lower than the target emission rate of 16.6$kg.CO_2/m^2.yr$. Also, given the carbon emissions "offset" due to the use of PV renewable energy which amounts to −17.7 $kg.CO_2/m^2.yr$, it makes the building defacto "carbon negative" to the value of −7.52 $kg.CO_2/m^2.yr$.

Being the residential property, in terms of energy consumption the majority of demand is attributed to the heating (35%), hot water (43%) and lighting (19%), totaling 97% of the overall consumption, as shown in Tables 3 and 4 (the appliances consumption is excluded). The estimated energy demand is 20.24 kWh/m^2, assuming the operational flow temperature of the heat pump 40°C. Using a lower flow temperature of 35°C, the energy consumption drops to 18.21 $kWh/m^2/yr$, and given that 19.23 kWh/m^2 /yr is estimated to be produced from the renewable sources, the net consumption becomes −1.26 $kWh/m^2/yr$, making it an "energy positive" proposal.

Table 1: Energy consumption, PV generation and CO_2 emissions estimates (scenarios 1–5).

Scenario	1	2	3	4	5
Heating demand (kWh/yr)	13389.0	13389.0	12103.0	12103.0	11778.0
Solar gains (kWh/yr)	0.0				
Internal gains (kWh/yr)	0.0	500.0	500.0	500.0	1500.0
Flow Temperature °C	40.0	40.0	35.0	35.0	35.0
Electricity for Heating (kWh/yr)	3648.2	3512.0	2967.5	2967.5	2628.6
DHW demand (kWh/yr)	2585.0	2585.0	2010.0	2010.0	2010.0
Electricity for DHW (kWh/yr)	982.9	982.9	764.3	764.3	764.3
Electricity appliances (kWh/yr)	3300.0	3050.0	2800.0	2550.0	2300.0
PV Power generation (kWh/yr)	6092.7	6092.7	6092.7	6092.7	6092.7
Overall (kWh/yr)	1838.4	1452.1	439.0	189.0	-399.8
CO_2 emissions (kg/yr)	964.4	761.8	230.3	99.2	-209.8

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Table 2: Energy consumption, PV generation and CO_2 emissions estimates (scenarios 6–10).

Scenario	6	7	8	9	10
Heating demand (kWh/yr)	11788.0	9266.0	9266.0	8451.0	8451.0
Solar gains (kWh/yr)					
Internal gains (kWh/yr)	1500.0	1500.0	3000.0	3000.0	3000.0
Flow Temperature °C	35.0	35.0	35.0	35.0	35.0
Electricity for Heating (kWh/yr)	2623.6	1986.2	1602.6	1394.1	1994.0
DHW demand (kWh/yr)	2010.0	2010.0	2010.0	1800.0	1800.0
Electricity for DHW (kWh/yr)	764.3	764.3	764.3	684.4	684.4
Electricity appliances (kWh/yr)	2050.0	1800.0	1700.0	1600.0	1500.0
PV Power generation (kWh/yr)	6092.7	6092.7	6092.7	6092.7	6092.7
Overall (kWh/yr)	–649.8	–1542.3	–2025.9	–2414.2	2514.2
CO_2 emissions (kg/yr)	–340.9	–809.1	–1062.8	–1266.5	–1319.0

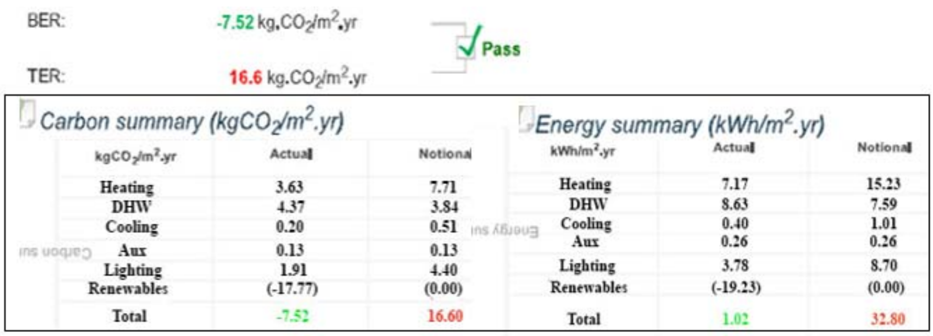

Figure 14: Part L energy summary report.

Table 3: Estimated energy consumption (conditioned area: 347m^2).

kWh/m^{2}yr	Heat	Cool	Aux	Lights	DHW	Renewables	Equipments
Jan	1.38	0.00	0.02	0.39	0.73	–0.37	0.70
Feb	1.04	0.00	0.02	0.33	0.65	–0.59	0.63
Mar	0.91	0.00	0.02	0.33	0.73	–1.22	0.70
Apr	0.76	0.00	0.02	0.28	0.73	–1.86	0.68
May	.027	0.02	0.02	0.26	0.74	–2.96	0.70
June	0.05	0.06	0.02	0.24	0.71	–3.35	0.68
July	0.01	0.19	0.02	0.25	0.73	–3.40	0.70
Aug	0.01	0.11	0.02	0.27	0.73	–2.50	0.70
Sep	0.09	0.01	0.02	0.30	0.72	–1.47	0.68
Oct	0.46	0.00	0.02	0.37	0.71	–0.76	0.70
Nov	1.02	0.00	0.02	0.36	0.69	–0.43	0.67
Dec	1.19	0.00	0.02	0.39	0.77	–0.31	0.70
Total	**7.17**	**0.40**	**0.24**	**3.78**	**8.63**	**–19.23**	**8.21**

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Table 4: Estimated carbon emissions (conditioned area: 347m^2).

kWh/m^{2}yr	Heat	Cool	Aux	Lights	DHW	Renewables	Equipments
Jan	0.70	0.00	0.01	0.20	0.37	–0.34	0.35
Feb	0.53	0.00	0.01	0.17	0.33	–0.55	0.32
Mar	0.46	0.00	0.01	0.17	0.37	–1.13	0.35
Apr	0.39	0.00	0.01	0.14	0.37	–1.72	0.34
May	0.13	0.01	0.01	0.13	0.37	–2.73	0.35
June	0.02	0.03	0.01	0.12	0.36	–3.09	0.34
July	0.01	0.10	0.01	0.13	0.37	–3.15	0.35
Aug	0.01	0.06	0.01	0.14	0.37	–2.31	0.35
Sep	0.04	0.00	0.01	0.15	0.36	–1.36	0.34
Oct	0.23	0.00	0.01	0.19	0.36	–0.70	0.34
Nov	0.52	0.00	0.01	0.18	0.35	–0.40	0.35
Dec	0.60	0.00	0.01	0.20	0.39	–0.28	0.35
Total	**3.63**	**0.20**	**0.12**	**1.91**	**4.37**	**–17.77**	**4.16**

5 CONCLUSIONS

The building used in this research has emerged from a novel design concept, including a distinctive approach to sustainable design and site contextual response, with design and build undertaken by a dedicated team of practitioners and researches. This makes it bespoke, but it does not undermine the importance of this project serving a useful learning precedent as a “one off” innovative design case study. The key conclusions are:

- The compressive and tensile properties of sycamore used are tested according to BS EN standards and proven to be similar to the published figures, although on a small sample of solid wood specimens from within the site boundaries.
- The assignment of visual grades and species in the BS EN 1912:2012 lists a German Standard DIN 4074 Teil 5, which gives grading rules for Acer Pseudoplanatus, ordinarily referred to in the UK as sycamore.
- It is essential to keep sycamore maintained at a moisture content of less than 20%, thus making it significantly less likely to be susceptible to a substantial fungal decay.
- The breathability of walls has to be protected to ensure a free moisture movement and thus prevent sycamore being exposed to prolonged periods of high humidity.
- Evidence of possible decay and issues with the moisture content and hardness of timber can be seen in weak areas on the junctions between the studs and base plate. It is important that their moisture content and rate of decay is measured regularly.
- It is important to dry the sycamore before installing it, in order to keep its moisture content as close as possible to its future in-service condition. (mc=14% for case study).
- There is a significant variation of sycamore moisture content observed over last 2 years, ranging from 6% to 21%, with the moisture content of sycamore situated within the external wall (SC 2) being significantly higher compared to the sycamore inside (SC 1).

In conclusion, the research demonstrates that sycamore could be used as a structural and constructional material, subject to due care taken to its service class uses, appropriate

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construction detailing for resistance to decay and insect attack, its moisture control and effective ventilation provision.

ACKNOWLEDGMENTS

Price & Myers – Structural Engineers, ARUP – Building Services Consultancy, Derek Latham – Architect and Home Owner. Vaillant UK – Building Services Installation.

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A SHAPE GRAMMAR APPROACH TO CLIMATICALLY ADAPTABLE FAÇADE SYSTEMS WITH REAL TIME PERFORMANCE EVALUATION

TUNG NGUYEN, BORIS CERANIC & CHRISTOPHER CALLAGHAN
Department of Architecture and Civil Engineering, University of Derby, UK

ABSTRACT

New computational techniques have been introduced to assist the design of adaptable building façades and to help quantify relationships between the building envelope and the environment. Designers increasingly use generative design approach for form-generation of building envelopes, and the organisation of components over a predefined form. In this research an original shape grammar approach for façade systems generation is proposed, with a rule-based method for the creation and exploration of complex shape composites based upon a set of simple initial shapes and predefined rules of composition. This is in order to explore a form finding of set of different building façade configurations before merging generated data into a simulated process of real-time daylighting and heat gains performance evaluation. The developed models adapt via responding to the data-regulation protocols responsible for sensing and processing building performance data in real time. The research reports on the prototype system development and testing, allowing continuous evaluation of multiple solutions and presenting opportunity for further improvement via multi-objective optimisation, which would be very difficult to do, if not impossible, with conventional design methods.

Keywords: kinetic façades, shape grammar, parametric design, performance monitoring, smart building environments.

1 INTRODUCTION

Adaptive façade systems can provide healthier internal environment whilst delivering substantial reductions in use of building energy and CO_2 emissions. Given the recent advances in the kinetic façades research, they have been identified as promising technological solutions for contributing towards sustainability targets of the 21st century, on the materials, components and systems level [1].

This research is inspired by traditional patterns and ornaments in Vietnam, seen as an important symbol of cultural heritage, especially in the era of globalisation where many countries are experiencing substantial transformations and beginning to lose links to their long standing historical traditions, including Vietnam. The research investigates how these aspects of spatial culture could be interpreted using shape grammar approach and used in creating novel façade systems that draw their inspiration from Vietnamese vernacular cultural identity, whilst at the same time satisfying modern building performance demands, such as a reduction in the energy consumption and enhanced indoor comfort.

There are numerous studies that research the benefits of grammar-based design generation and implementations [2]–[4], in particular through the concepts of parametric design [5]–[8]. In those hybrid systems, a grammar-based algorithms are responsible for generation of different design iterations, whilst parametric design tends to control alternation to a permitted variations of set parameters.

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180121

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2 SHAPE GRAMMAR PATTERNS DEVELOPMENT

2.1 Vietnamese spatial patterns and design

Patterns are fundamental feature observed in spatial design (interior, architectural, urban and landscape). The word “pattern” is derived from the Latin “pater”, or “patronus”, meaning father, patron, or protector, resulting in the conception of pattern as a model, example or mould. Modern examples of patterns typically involve repeating units, arrangements or developments of identical or similar elements. Garcia [9] stated that this diversity of meanings delivers multiple types of patterns in the creation, reproduction and evolution of spatial arrangements.

Vietnamese architecture is traditionally perceived as an architecture of relationships (between interior and exterior, between people and the nature, etc.), rather than that of forms and masses. Given its climate, the houses in Vietnam had always been very light, both visually and constructionally (see Fig. 1). They were not built from columns and walls, but from pavilions and covered walkways, lobbies and gardens, all connected though purposely designed routes and passages. Whilst in other countries spaces were often perceived as enclosures formed by substantial walls, spaces in Vietnamese houses were perceived through a sequence of thin screens organised through spatial patterns. In fact, they were often built by using light, movable partitions made of bamboo and wooden frames, such as wooden screens, bamboo folding curtains and sliding doors, always having a certain degree of transparency and permeability. As a result, Vietnamese patterns are open and flexible, emerging as organically generated designs that combine simple shape elements into a more complex composites, informed by the concept of generative design. Given their distinct and

Figure 1: Left: Decorative lattice screens as means of passive ventilation and light control. Right: rotatable door panels with traditional patterns. *(Source: Author.)*

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Figure 2: Left: Decorative lattice screens as means of passive ventilation and light control. Right: A movable and foldable curtain wall screen with traditional patterns. *(Source: Author.)*

broad qualities such as adaptability and repeatability, patterns in Vietnam are depicted as fundamental to structural, aesthetic or energy considerations in design.

With the advent of modern digital technologies new spatial layout theories are emerging, such as generative, algorithmic and parametric design, allowing new types of spatial pattern, sometimes never seen before, to occur. In this research both traditional and modern are merged within the environmental performance context, considering the potential of novel generative patterns design approaches in relation to the design of modern building façade systems and components.

In terms of socio-cultural impact, a compact symbolic form patterns can provide not only information about the cultural history of an ethnic group but also act as catalyst of self-identification in the society, contributing to cultural and spiritual self-development. They represent a form of universal understanding in a visual symbolic form, a visual archetype of decorative forms that signify cultural identity.

2.2 Shape grammars development

Shape grammars (SGs) are a generative design systems that can analyse and produce complex shapes based on a set of initial shapes and series of predefined shape rules. SGs have been used to explain the language of designs such as ornamental art [5], [10], architecture [4], and Islamic patterns [3]. Current implementations have demonstrated how designers take advantages of SGs generative capability [6]. Indeed, shape grammar has been used to capture the cultural gene of designs of for example Chinese ice-ray lattice designs by Stiny [11] , the design of Mughul gardens by Stiny and Mitchell [12], Queen Anne style houses by Fleming [8], Taiwanese traditional vernacular residences by Chiou and Krishnamurti [4], traditional Turkish houses by Çağdas [3], classical Ottoman mosques by Şener and Görgül [13], Siza's Malagueira houses by Duarte [6] and by Strobbe in engineering design [14]. Most of these studies concentrate on spatial layout planning or in other words, two-dimensional shapes transformations on a horizontal plane, based on basic input parameters of space such as length, width, etc.

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As defined by [15], “a shape grammar is a quadtuple (VT, VM, R, I), consisting of a finite set of terminal shapes (VT) and marker shapes (VM), a finite set of shape rules (R), and a non empty set of initial shapes (I) that is part of VT < VM. The shapes defined in the set VT < VM form the basic elements for the definition of shape rules in the set R and the initial shape I.” New and more complex composite shapes are then generated by the rules being applied, recursively and iteratively, to the initial shape. This formation of language of shapes occurs through Euclidean transformations (t), such as translation, rotation, scaling and other linear transformations. Rule application results in “subtracting” the transformed shape A from previous C, and “adding” the transformed replacement shape B (then-part). This results in a new shape C’ = C – (A) + t (B).

Stiny [11], one of the original originators of shape grammars, demonstrated that SGs can produce most of the Chinese lattice designs in a very simple and intuitively compelling way (see Fig. 3). He also successfully defined a parametric shape grammar that can describe the constructing process of Chinese Ice-ray patterns. Later, Majewski and Wang [10] *and Stiny* [11] undert*ook* an algorithmic method to the formation of Chinese lattice patterns and represented them in seventeen types of plane symmetry groups of patterns. This popularity of Chinese lattices patterns research is due to having both cultural meaning and being conducive to the shape grammar computational interpretation.

In this research a shape grammar for typical Vietnamese lattice designs was explored, found on doors and windows used as decorative features, whilst at the same time providing effective means of passive ventilation and light control. They typically are on vertical planes and in this work serve a different purpose – designing and controlling the shading opening (façade aperture) to adapt to change in external climate conditions.

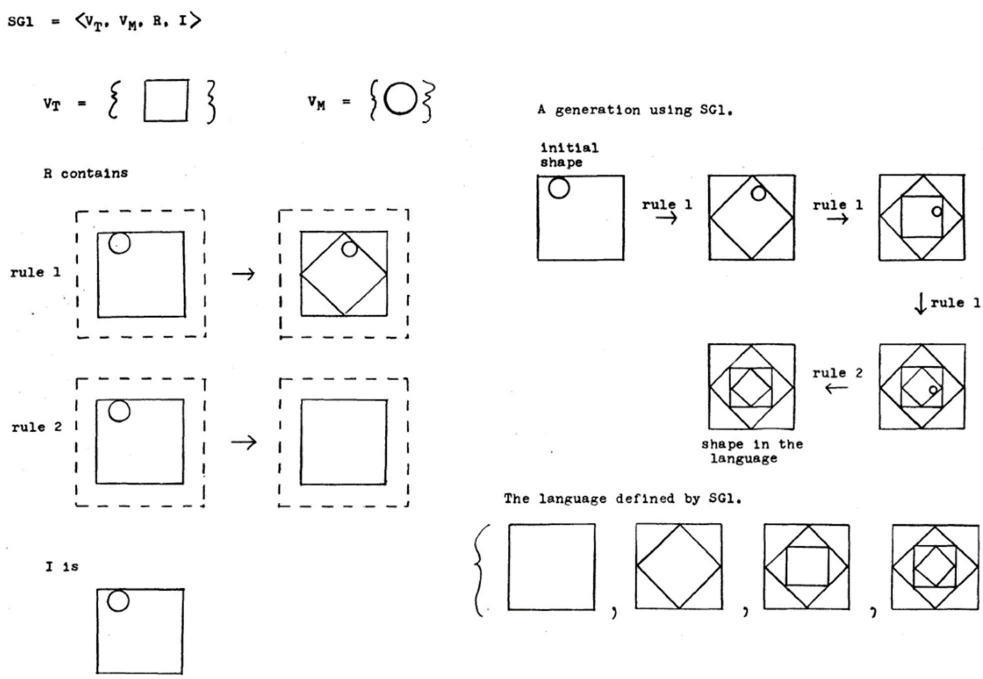

Figure 3: A shape grammar for Inscribed squares [11].

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Their potential was evaluated in terms of indoor comfort, namely effectiveness of natural daylight control and protection against excessive solar heat gains. Shape Grammar Interpreter (©SourceForge) was used for an initial shape generating process because of its ability to effectively configure rules, produce a multitude of iterations with complex composites and visually display final results (see Fig. 4).

The method proposed in this research is to use shapes extracted from the traditional Vietnamese lattice patterns found in literature, such as I, L, S, H shapes, or combination of them, in a designed shape grammar generation process. This process has two inputs: an initial shape and a shape transformation rule(s), where the rule and its repetition lead to a complex shape composites generation (see Fig. 5). In fact, each node of the lattice represents a shape

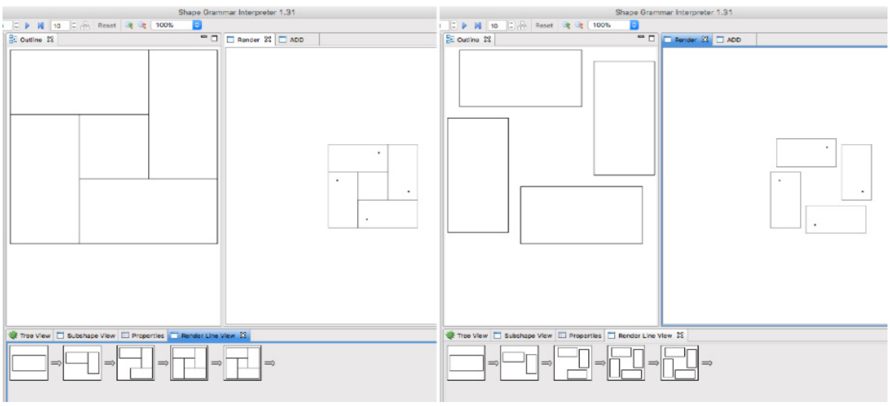

Figure 4: An example of Shape Grammar Interpreter uses straight lines as basic elements for rectangles. *(Source: Author.)*

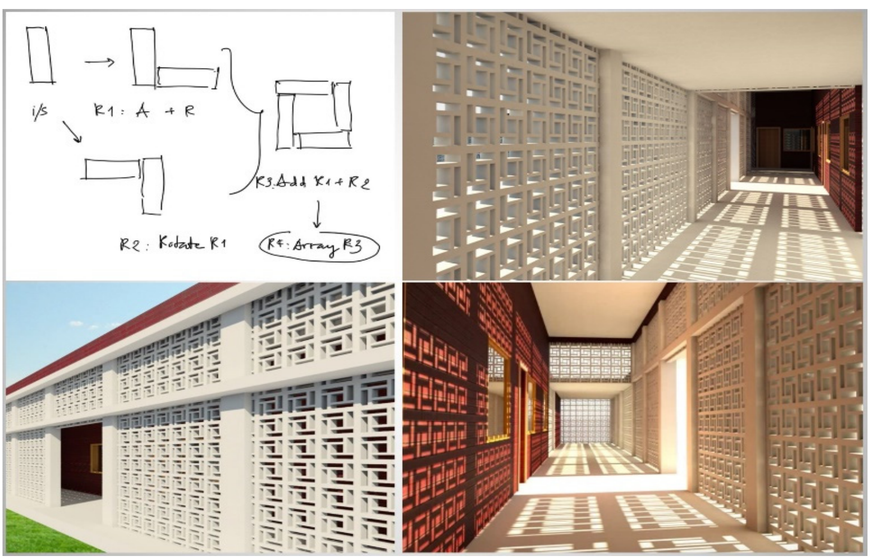

Figure 5: A concept of solar shading device, for a corridor, made of Shape Grammar developed in Fig. 4. *(Source: Author.)*

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element that is a maximal shape of a combination of such elements including both sub-shapes that are parts of the initial shape description and emergent shapes.

The development begins with defining a vocabulary of two dimensional shapes and their transformation rules. The shapes in these scenarios are made up of the various elements that form the lattices, for example, frame, sub-frame and blocks. Indeed, an initial shape “I” (for rectangle shapes) and 2-d transforming rules, such as move, rotate, add, join and mirror are used. More specific, the generation of a lattice design is based on the manipulation of rectangles as the lowest level constituents. Fig. 5 demonstrates how simple rules can quickly generate complex composites, which could be legibly used in the architectural design as a building components. In particular, the pattern consists of two structures: the global structure and the local structure or the motifs, in which the main evolution process emerges [16].

3 BIM SDA SBE SYSTEM DESIGN DEVELOPMENT

3.1 BIM SDA SBE

Asset monitoring and evaluating the performance of a building compared to its simulated performance through sustainable design analysis (SDA), is implemented through building management systems (BMS), that are increasingly connected to building information models (BIM). Automating this process through programming and system optimisation leads to intelligent and dynamic buildings, or smart building environments (SBEs) with sufficient reasoning to intelligently control building energy usage (see Fig. 6), whilst ensuring comfort and support for any occupants [17], with façades for example that can adapt to the environmental conditions both around and within the building, in the real time [18].

Developing a prototype BIM-SDA-SBE application [19], involved connecting a building information model created in ©Autodesk Revit to the sensors in the real world using ©Autodesk Dynamo visual programming language [20] to collect and evaluate real time sensor data readings, and then programming the intelligent kinetic façade climatic response, either via controlling the façade system apertures or their shading angles. An Arduino Uno Board has been used to take readings of current room conditions, notably temperature using a DHT22 sensor, and light (lux) using a TSL2591 sensor (see Fig. 7).

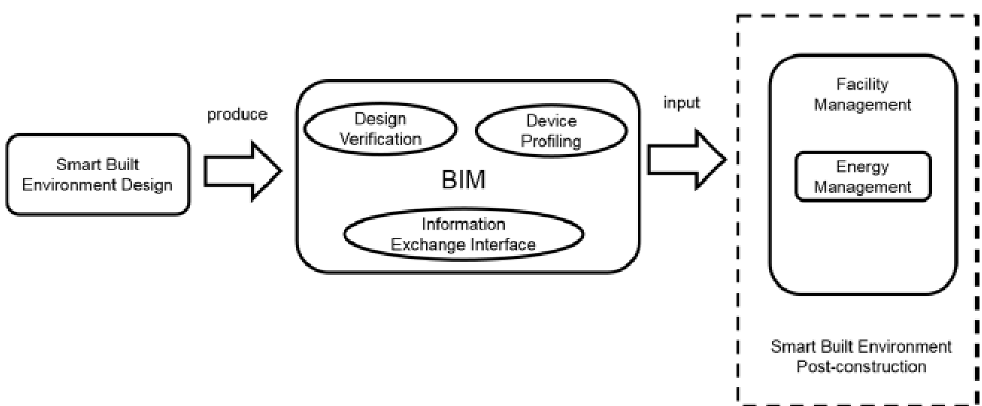

Figure 6: Concept of BIM and SBE integration [17].

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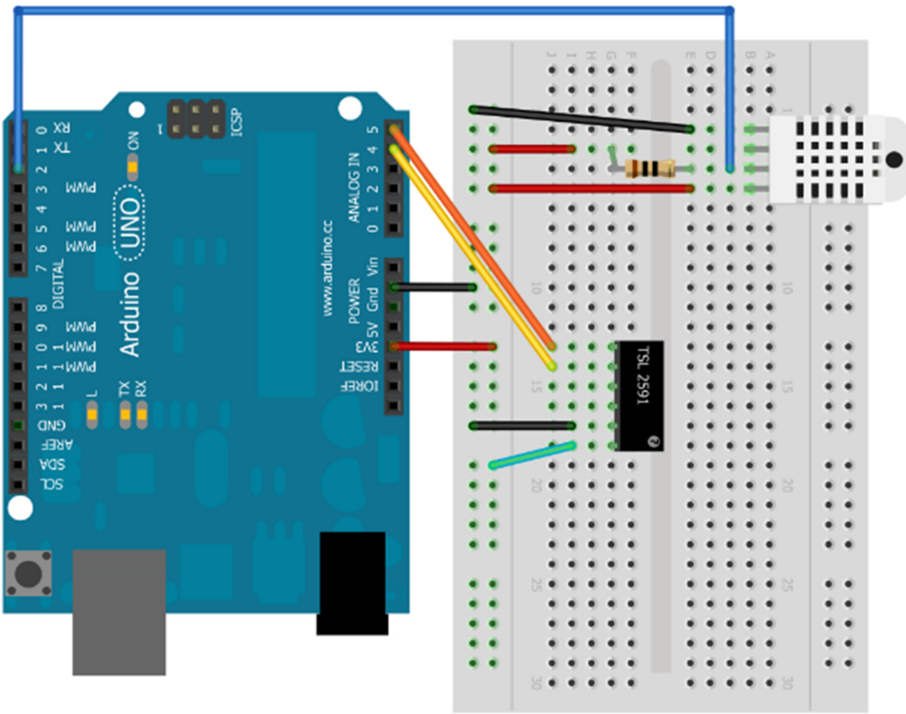

Figure 7: Ardiuno and sensor wiring layout for real time temperature and light data. *(Source: Bruce J, 2011.)*

3.2 System implementation

To form the bridge between sensors hardware and visual programming environment the research has used Dynamo package called Firefly [21], enabling computer programme to read sensor data real time, in a useable format. Employing an intermediary system to control the flow of data mimics the behaviour of a typical BMS systems, where dedicated sub-systems are used to perform different linked functions.

Early evaluation solutions involved applying linear regression to the collected data to predict the future conditions, building a temperature profile for the conditions like those used in the building performance evaluation. The intention with a fully deployed system is to have a simulated temperature profile which would then be modified to reflect the condition data being reported by the sensors in the real time. Developing temperature and reaction profiles for all seasons and conditions enables more informed decisions to be made.

Temperature results are evaluated against the defined comfort conditions (see Fig. 8). Depending on real time sensors readings in relation to 21°C +/-3°C adopted thermal template and 300–500 required lux level conditions for this case, the opening angle of the façade shading panels is adjusted. As part of the linear regression approach, data was cumulatively evaluated in 30 minute groupings to determine the likely temperature and light values 30 minutes later. Changing the façade shading panels angle more frequently than every 30 minutes would likely result in disturbance for the occupants without major gains in terms of more effective control of heat gains and access to the daylight.

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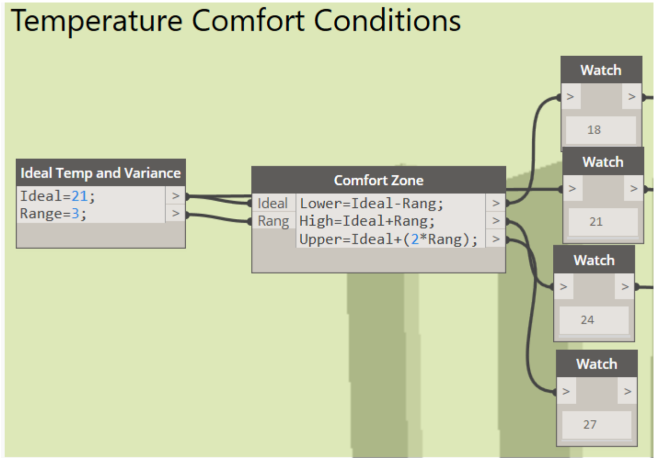

Figure 8: Dynamo graph group for assessing the temperature comfort conditions. *(Source: Authors.)*

Determining the correct aperture of solar shading device needs to rely not only on the indoor comfort data analysis but also the external climate data simulation. For example, incorporating weather, sun position and room characteristics enables adaptable solutions which react to not only what is typical or predicted, but the actual conditions. This is achieved by linking data and geometry from a building information model in real time (see Fig. 9).

Solar Analysis was carried out with nodes for getting the local weather data and the position of the sun relative to the position of the building being visually programmed in (see Fig. 9). The sun Azimuth and Altitude are carried forwards to the solar control nodes as these give the relative position in relation to the elevation. Relating the Sun Path to the location and orientation of the façade allows the shading angle of the panels to be optimised for each shading array, enabling a curved or multifaceted façade systems to be evaluated more appropriately.

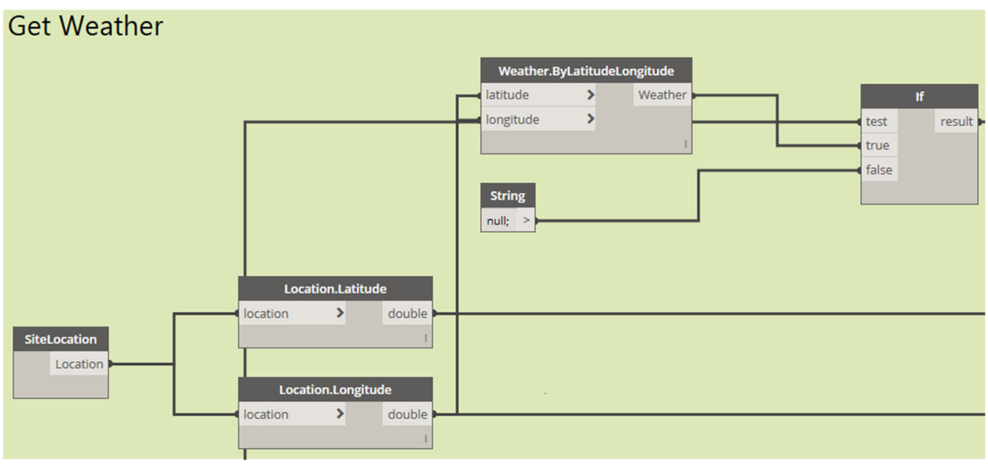

Figure 9: Dynamo graph for getting weather at model location. *(Source: Authors.)*

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Using the package "Solar Analysis for Dynamo" it was possible to determine the values of solar insolation (see Fig. 10). Calculations are run in parallel for when the openings to a room are unshaded, and when the shading at the determined angle is included [22], [23]. Simulated energy levels can be displayed in a coloured grid pattern giving the designer vision of where the shading is being more effective. Calculating the Net Solar Gain in both shaded and unshaded conditions, gives the heat gains input difference which depending on whether it is positive or negative, will provide the heating or cooling benefit. Recording these values enables adjustment in the calculation to optimise the required temperature reduction.

4 RESULTS

Fig. 11 shows the shading angle data plotted against the temperature. In the linear regression scenario, temperature was the main parameter with the light levels adjusting the shading angle accordingly. However, compared to the temperature there is less of a coloration, which could be partly explained by the temperature control factor introduced for temperatures above the upper limit of the comfort zone of 23°C. From 0 to 110 minutes the temperature was above 23°C, which resulted in an extra 10% added by the temperature control factor to the turning angle of shading device to decrease the solar radiation and thus more rapidly prevent overheating.

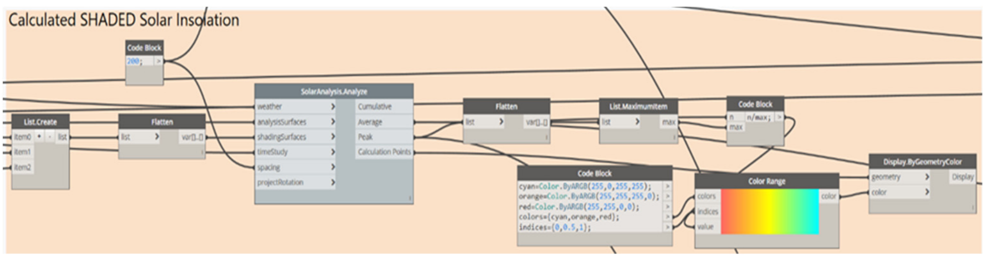

Figure 10: Dynamo Group with calculated data directed to a coloured grid. *(Source: Authors.)*

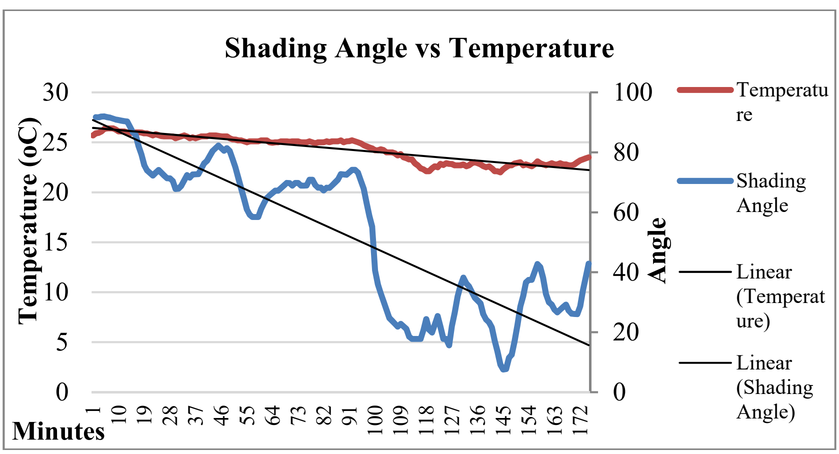

Figure 11: Graph showing shading angle in relation to temperature, including linear trend lines. *(Source: Authors.)*

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Fig. 12 shows the effectiveness of the shading by comparing shaded and unshaded solutions involving sun, weather and location information. When considered in context of the other heat sources in a room, reducing the overall solar gains can significantly contribute to reduction in overall temperature. In hotter climates where mechanical cooling systems are often employed this should significantly reduce the cooling load required [24].

5 CONCLUSIONS

The research integrates smart façade shading systems and intelligent control of their real time response with a unique and vernacularly sensitive approach to their design through application of shape grammar. The latter is conceived as a generative rule-based concept for the creation and exploration of complex shape composites, founded upon set of initial shapes inspired by traditional Vietnamese patterns and their composition rules. The developed prototype model adapt in real time via operating upon communication and data-regulation protocols for sensing and processing building performance information, based on the integration of shape grammar, building information modelling (BIM) and system optimisation. The method for integration of building performance simulation with the building energy management system (oS-BMS) into smart building environments (SBE) based on the open source, has been presented and also been considered, and a prototype structure for their amalgamation has been established.

As reported in the research, the "proof of concept" for the sensor-actuator control has already been developed via BIM based visual programming and virtual sensors with IFC shared parameters, distinctively defining a sensor model and type. Thus virtual objects, in this case kinetic façades systems, are able to self-actuate and regulate light levels and solar heat gains of the actual building component, via its real time sensor-actuator connection. This is based on the results of visual programming algorithms that uses information from a "virtual to real" sensor data within the BIM environment [19].

In its next phase, the research will move onto "proof of prototype" via a scaled physical model investigation. In this phase of prototype construction and testing, the developed SDA-BIM-SBE integrated building performance monitoring and management system will be examined on its ability to provide an advanced energy management through a deployment of system analysis and optimisation algorithms.

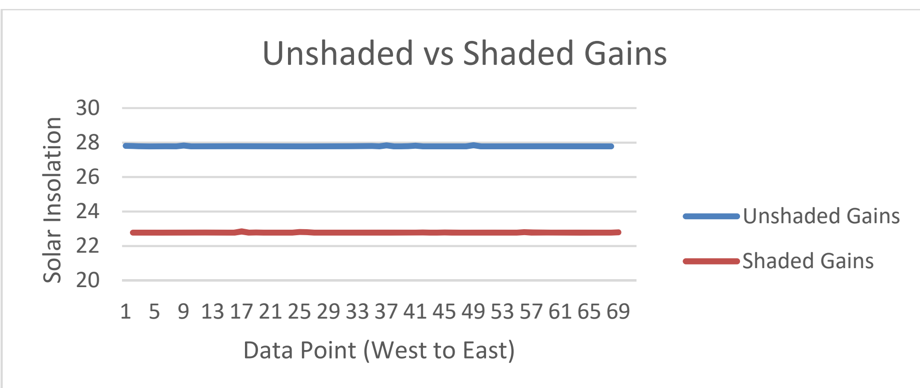

Figure 12: Graph comparing solar insolation in simulated shaded and unshaded conditions. *(Source: Authors.)*

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HYGROTHERMAL SIMULATION: USE FOR SERVICE LIFE PREDICTION AND MAINTENANCE OF FAÇADES

MATHEUS NASCIMENTO[1], JEFFERSON GONÇALVES PEREIRA[2], GUSTAVO LIRA ALVES[2], VAMBERTO DOS SANTOS FILHO[3] & ANDRÉ A. NÓBREGA DANTAS[4]
[1]Centro Universitário Euro-Americano (UNIEURO), Brazil
[2]Gonçalves Engineering Company, Brazil
[3]Instituto de Educação Superior de Brasília (IESB), Brazil
[4]Instituto Federal de Goiás (IFG), Brazil

ABSTRACT

The façade cladding of a building is a system responsible for providing and maintaining the comfort of the indoor environment as both thermal and acoustic insulation, as well as protecting the building envelope from weathering agents. Moreover, these systems have visual, aesthetic and cultural purposes. One of the most used façade coatings is ceramic tile, which is able to provide appropriate resistance to weather, but with an elevated rate of degradation. Such downside results are the loss of performance, quality and that the building may not reach its estimated service life. For this reason, the adaptation of architectural design to the natural environment is important. The present paper aims at measuring the action of weather agents on a sample of three buildings under construction in Brasília, Brazil. We used hygrothermal simulation software, WUFI Pro 6.0, to quantify the results for wind-driven rain, radiation and temperature on the north, south, east and west orientation of these buildings. The results of global radiation and wind-driven rain presented the same order of incidence, and the most critical values occurred during the dry period, for the north and west orientations. The variations of surface temperature in general reached maximum values on the north and west façades. A temperature gradient was also quantified, revealing a similar trend to the previous results. Furthermore, results were useful in identifying maintenance strategies and for service life prediction for the three buildings' casings, and show advances in the design phase, by learning from nature and traditional construction techniques.
Keywords: Brazil, building façade, building degradation, building design, ceramic tile, construction, hygrothermal simulation, maintenance, tiled exteriors, weathering.

1 INTRODUCTION

A ceramic tile coating is one of the main types of systems used on building façades. Its broad use is explained not only by the aesthetics, but also by the resistance and durability provided, when compared with mortar coatings; however, both new and old construction with this solution do present constant anomalies, originated in different ways, through planning, design, execution, low-quality materials, weather, incorrect building use, and lack of maintenance [1].

Within this context, degradation can be defined as a process whereby one or more properties of the materials are affected by the action of degradation factors, causing a reduction in the level of performance [2]. Degradation factors are those that adversely affect the performance of the buildings, and they are: atmospheric, biological, load, incompatibility and due to use [3]. In its initial phase, the degradation process may not be noticeable; but when the anomalies become evident, they start a decision process that verifies the need to intervene with maintenance [4]. The main pathological manifestations that present in ceramic tile coatings from different degradation factors are: coating detachment, cracking, efflorescence, sealing failure, and staining, to name a few.

When analysing the relationship between degradation and performance of the systems in a building, the importance of performing maintenance activities becomes evident. Such activities may have two main origins: the preservation of material durability in a proactive

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180131

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way (preventive); and corrective, initiated after the appearance of pathological manifestations or when the system no longer performs its function satisfactorily [5]. For ceramic tile coatings, many aspects of maintenance need to be observed. In a preventive way, periodic inspections to verify the stability of the coatings should be in place. In addition, approximately every five years, users are responsible for replacing movement joints [6]. For the corrective measures, users need to replace ceramic tile that detaches; correct points with cracks, sealing failures; target maintaining the service life, durability; and protecting users.

One of the main factors responsible for generating pathological manifestations in the buildings' façades; and consequently, reducing performance are weather agents, which can cause physical and chemical alterations in the buildings and in their components. Radiation, wind-driven rain and variations of temperature are important examples of these degradation factors [7]. Therefore, the knowledge of the conditions of façades' exposure to weather factors allows for a broader understanding of the interactions between nature's agents and degradation processes throughout the service life of the building. In this way, it is possible to adapt architectural design to the natural environment, learning from nature and traditional construction techniques in Brazil and many other countries.

Software packages for hygrothermal simulation can be used as a tool for quantification of the weather agents [8]. One example of these packages of software is WUFI [9], developed by the Fraunhofer Institute for Building Physics (IBP). With this tool, the user can calculate the transient transport of heat and moisture in different construction materials. The hourly output data can be presented in terms of the systems (variations of temperature and moisture properties); and in consideration of the environment conditions (radiation, temperature, moisture, wind-driven rain). The results can be combined with the degradation process in a post-processing simulation; in order to associate the damages caused by temperature and moisture, and how they act in the degradation of the studied systems [10].

The goal of this paper is to measure the action of weather agents in a sample of three buildings under construction in Brasília, Brazil, using hygrothermal simulation software.

2 METHODOLOGY

The method is based on the use of WUFI® Pro 6.0 software as a tool for quantification of weather agents and for assessing the degradation of the façades studied. First, our selection of the buildings in Brasilia, Brazil was established with three buildings under construction having ceramic tile coating on their façades, taking into account different colour bands: light, medium and dark. After that, the three cases were simulated with WUFI and the results were presented in terms of quantification of the weather agents and the buildings' response, which allowed the influence in the degradation process.

2.1 Building casing

In this study, we targeted buildings located in Brasília, Brazil, where the city plan and regulations limit all the residential buildings in the central area to six floors. The façades of the chosen samples are totally or partially coated with ceramic tile. The selection of samples was decided by means of surveys, where we searched for buildings under construction with colours used in the light, medium and dark bands of colours. The three buildings, named as A, B and C; are represented in Figs 1–3.

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Figure 1: Building A (light colour tile used).

Figure 2: Building B (medium colour used).

Figure 3: Building C (dark colour used).

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2.2 Simulation

For the hygrothermal simulation using the WUFI PRO 6.0 software, it is necessary to determine parameters according to the place of study, for the insertion of data. The characteristics of the buildings should be defined, such as: materials, orientation of façades, wind-driven rain, coefficient of absorptivity (α), simulation period, and outdoor and indoor climate [8]. The software uses a calculation method based on transient regime and it is possible to obtain hourly output data of the climate of the exterior and properties related to the temperature and moisture of the studied materials [9].

Fig. 4 shows the constructive element adopted and represents the ceramic tile coating on the façades of the three buildings studied [9], [11].

The WUFI software contains an extensive database of properties of construction materials, and the main definitions of parameters [9] of input data below (general definitions) and in Table 1 (materials' definitions):

- Wind-driven rain: using the WUFI® method of calculation, with a reduction coefficient of 0.7;
- Height: high building from 10 to 20 m (representing six floors);
- Heat resistance: Exterior surface – 0.04 m²K/W; Interior surface – 0.13 m²K/W [6];
- Absorptivity (α): Building A – 0.3; Building B – 0.5; Building C – 0.7 [6] represents the amount of radiation energy absorbed;
- Initial conditions: initial relative humidity (80%) and temperature (25°C) [10];
- Simulation period: 01/01/2017 to 31/12/2020, using data referring to the last year, when the initial moisture stabilization had occurred [11];
- Climatic data: TMY (Typical Meteorological Year) file for Brasilia, Brazil [12];
- Indoor climate: according to [10].

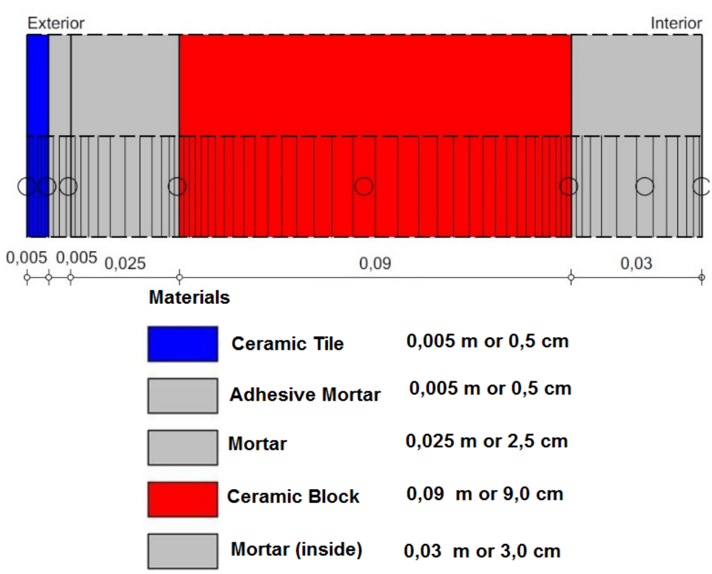

Figure 4: Ceramic tile coating system used (layer size represented in meters), as per [9] and [11].

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Table 1: Materials parameters from [9] and [11].

	Bulk density	Porosity	Specific heat capacity	Thermal conductivity	Water vapor diffusion resistance factor
Units	kg/m³	m³/m³	J/kg.K	W/m.K	[-]
Ceramic tile	1,730	0.290	868	0.490	116
Adhesive mortar	1,450	0.260	850	0.800	18
External and internal mortar	1,755	0.210	850	0.800	28
Ceramic block	578	0.486	850	0.158	23

2.3 Weather conditions

The climatic archive (.epw) was used, from the measurement scale of the National Institute of Meteorology in Brazil (INMET) [12]. This took place in the 2000–2010 period, and the Laboratory of Energy Efficiency in Buildings (LABEEE-UFSC) reasserted this data in 2016. The file contains 8,760 hours of weather data (radiation, temperature, wind-driven rain and relative humidity), proven to be representative for Brasília, Brazil [13].

The archive provided by LABEEE-UFSC is composed of climatic variations; it is possible to characterize the cyclical and seasonal behaviour of climate throughout the year, taking into consideration the average values, maximums and frequencies of occurrence due to hourly data provided from the software [13]. Fig. 5 demonstrates a summary of the climate file.

By analysing the graph provided by the WUFI Pro 6.0 software (Fig. 5), the solar radiation incidence is higher in the northern orientation (1,015 kWh/m²); followed by: eastern (917 kWh/m²); western (911 kWh/m²); and southern (639 kWh/m²) orientations. The wind-driven rain follows the same incidence index in the façades, with a normal rain amount of 1,093 mm/year. The mean wind speed is 2.46 m/s, the maximum temperatures are: 32.7°C; 21.1°C for mean, and 11.2°C for minimum. The relative humidity presented: 97% for the maximum, 66% for the mean, and 17% for the minimum.

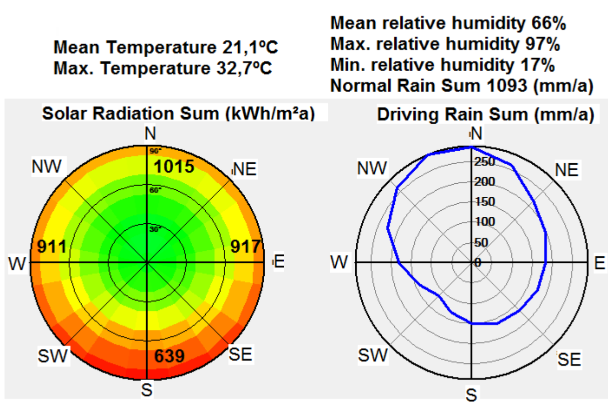

Figure 5: Climate from Brasília [9].

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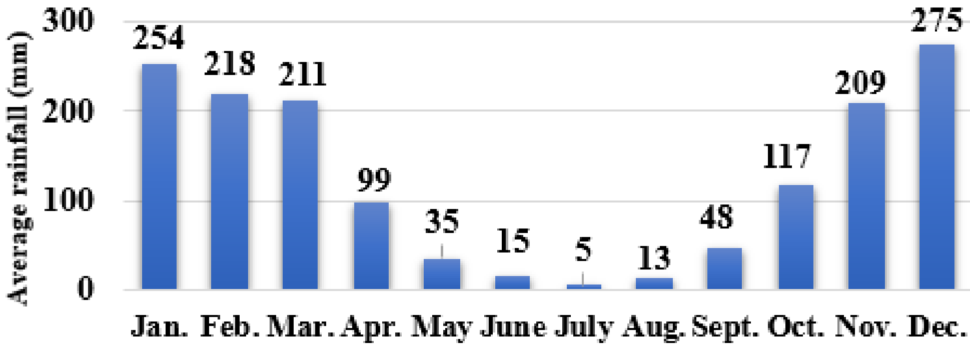

Figure 6: Average rainfall in Brasília [14].

In Brasília, the so-called drought months are from April to September, comprising a six-month dry period [14]. Whereas, the other six-month period (October to March) is the rainy season. Fig. 6 shows the monthly rainfall average in the Federative Union of Federal District, where the observation of the two above-mentioned periods during the year is evident.

2.4 Output data

One can extract output data from the WUFI on an hourly basis, for all parameters analysed and based on the WUFI instructions [9], which state that the hourly data will be about the distribution of temperature and heat fluxes in materials with temporal variations; and the moisture content (g), relative humidity (%), and distribution of moisture flow in the materials, considering temporal variations.

The post-processing step is associated with the application of the collected results of the simulations [10]:

- Wind-driven rain: rainfall on the surface of the façade due to the action of the wind on precipitation, for all studied buildings;
- Radiation: global value that affects all façades (north, south, east and west orientations);
- Surface temperature, and daily thermal amplitude for all buildings.

This study focused on the degradation of the envelopment of buildings, especially the degradation caused by weather actions such as wind-driven rain (moisture), solar radiation, and temperature variations.

3 RESULTS AND DISCUSSION

The rainy season in Brasilia occurs between September and April. According to a rainfall study [14]; May, June, July and August are the driest months of the year. The six rainiest months of the year (October, November, December, January, February and March) identified correspond to 92% of the total precipitation. Consequently, 8% of the total precipitation corresponds to the six driest months (April, May, June, July, August and September).

Using the data extracted from the WUFI 6.0 simulations, it was possible to obtain the incident wind-driven rain in the four cardinal directions. The order of incidence is: north (143.03 L/m²; 35.8%); east (91.4 L/m²; 22.9%); west (89.89 L/m²; 22.5%), and south (74.79 L/m²; 18.7%), as seen in Fig. 7.

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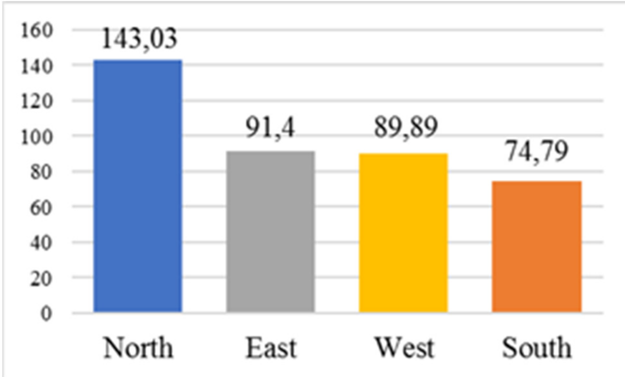

Figure 7: Wind-driven rain (L/m²) obtained from simulation (annual values).

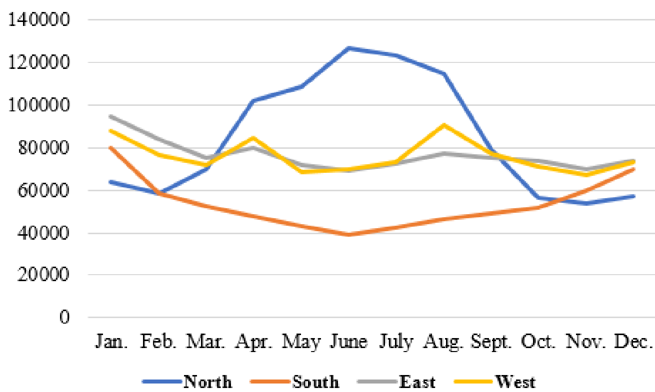

Figure 8: Radiation (W/m²) obtained from simulation with monthly values.

The results obtained by the simulation for global solar radiation are shown in Fig. 8 (monthly accumulated values) for the period of one year; in the north, south, east and west orientations.

One can observe that during the dry period (April to September), the northern façade receives the highest incidence of solar radiation (18.8% of the total sum of all façades). A previous study [11] showed that the dry season is mainly responsible for the degradation of buildings, especially degradation caused by thermal variations. During the entire rainy period (October to March), the southern façade receives a higher incidence than the northern façade (except during March and October), but less than the eastern and western façades, according to Fig. 8. It is indisputable due to the evidence that differences occur in the seasonal effects in Brasília. The software proved to be a good tool for identifying these variances. In others studies, the software had already substantiated different kinds of climate change and variations [15].

When considered, the accumulated values the northern façade show it is the most critical side (29.1%); followed by east (26.3%); west (26.2%), and south (18.4%) orientations. This order is exactly the same as what is obtained with wind-driven rain values.

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Table 2: Superficial temperature (°C): average and maximum for the annual dry and rainy periods in Brasilia, Brazil.

Building	Cardinal direction	Average annual	Maximum dry	Average dry	Maximum rainy	Average rainy
A (α = 0.3)	**North**	25.5	38.3	25.2	43.7	25.9
	South	24.5	38.3	25.3	37.9	23.8
	East	25.3	41.1	25.8	41.5	24.7
	West	25.3	46.0	25.7	44.3	24.8
B (α = 0.5)	**North**	26.1	39.8	25.5	46.7	26.6
	South	24.9	39.7	25.7	39.0	24.1
	East	25.9	43.8	26.3	43.7	25.3
	West	25.8	49.1	26.1	46.6	25.4
C (α = 0.7)	**North**	27.0	42.9	26.1	51.5	27.8
	South	25.5	42.1	26.3	40.7	24.6
	East	26.6	48.0	27.2	47.1	26.0
	West	26.5	54.1	26.9	50.2	26.2

For temperature, the study used the maximum and average obtained on the surface of the buildings. The mean values of external surface temperature were presented for the annual, dry and rainy periods, and the maximum for the dry and rainy periods is shown in Table 2. It is paramount that the software provide hourly data for these parameters, but the present paper had focused on a macro analysis. Other studies have shown that the software is able to evaluate microclimates (inside and outside), considering the hourly data provided [11], [13]. Global solar radiation influences external surface temperature, the variation of external air temperature, and hygrothermal characteristics of the construction system, to name a few.

When analysing Table 2, one observes the behaviour of external surface temperature values, which vary throughout the year. Building A (α = 0.3), had the lowest value (annual average) of 24.5°C for the southern façade; while the highest maximum annual average value was 27.0°C for Building C (α = 0.7) on the north façade. When analysing the annual average temperature of all the orientations, it was possible to classify the façades in descending order: north, east, west and south.

Scrutinizing the extremes of the maximum and minimum temperatures of the buildings, one realises that there was some variation between the maximum values of the façades. The maximum value was 54.1°C, which occurred in the dry period on the western façade of Building C (absorbance -0.7). All other buildings also had the maximum temperature in the western orientation (the absorbances of 0.3 and 0.5 had values of 46.0°C and 49.1°C, respectively). With the focus on the minimum values, it was observed that the values are constant for all façades studied (13.3°C for the rainy period and 17.4°C for the dry period).

Another way to investigate the temperature parameter is the value of ΔT. This can be calculated using the maximum *(Tmax.daily)*. and minimum *(Tmin.daily)* surface temperatures differences during a day, according to eqn (1).

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$$\Delta T = Tmax.daily - Tmin.daily. \quad (1)$$

For this calculation, all the daily values of the three buildings studied and the maximum were taken into consideration, as well as average (annual, dry and rainy) periods, as shown in Table 3.

Table 3 shows that the maximum ΔT value (27.8°C) obtained for the dry period occurred for the northern façade. In the rainy season, the maximum (29.6°C) occurs for the western façade. For both cases, the maximum values occur for Building C, which has the highest absorbance (α). In this sense it is also possible to observe, as well as in the individually analysed temperature parameters, an increase in the values of ΔT according to the growth of the absorbance presented by the buildings.

The minimum ΔT values show little variation, even when the dry and rainy periods are compared. The mean values for the minimum variation observed were 2.5°C for the dry period and 3.6°C for the rainy season. With this, it is noticed that the minimum ΔT of the rainy season increases in relation to the dry. This could have occurred due to the decrease of surface temperature of the façades caused by periods of higher incidence of rains.

The comparison of the maximum values between the dry and rainy periods reveals a greater difference of ΔT, especially for the northern orientation. In Building C, for example, the difference reaches 7.6°C. The comparison of two periods reveals a trend of higher averages in the dry period in the northern, western and eastern orientations.

The comparison on the results of radiation, wind-driven rain, temperature and ΔT, is a tool for observing that façades are mostly influenced by these parameters on the north, west and east; followed by lower values presented for the southern façades. This trend may influence a higher degradation of the north and west façades. This has also been observed in previews studies [11], [13]. With these results, it is clear that the WUFI software was able to quantify the weather incidence presented in the studied buildings. This software can be a tool used in the design of new buildings, as there is a great availability of climatic archives (.epw) for the whole world. This is a study that might be replicated; and consequently, generate good results for other cities and countries.

Table 3: Temperature gradient (ΔT in °C): Maximum and average temperatures for three tiled buildings during dry and rainy periods, and annually.

Building	**Orientation**	**Average annual**	**Maximum dry**	**Average dry**	**Maximum rainy**	**Average rainy**
A (α = 0.3)	North	11.9	18.6	14.0	14.0	9.8
	South	10.2	14.5	10.6	14.1	9.8
	East	16.5	22.6	16.8	23.2	16.2
	West	12.6	18.3	13.6	19.6	11.6
B (α = 0.5)	North	14.7	23.2	17.8	17.0	11.7
	South	11.8	15.7	11.9	16.4	11.6
	East	13.5	18.9	13.8	18.9	13.2
	West	15.7	22.0	16.8	19.5	14.6
C (α = 0.7)	North	17.6	27.8	12.6	20.2	13.6
	South	13.3	16.9	13.2	18.7	13.5
	East	16.5	22.6	16.8	23.2	16.2
	West	18.9	26.6	20.1	29.6	17.7

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The WUFI software proved to be useful for defining maintenance strategies, because it is possible to determine the most critical orientations due to climate change and these façades can be given special attention during the service life of the building. Movement joints need to have special definitions, both in the design stage and in maintenance, mainly for northern and western façades, for instance, considering the results obtained. Due to the most critical thermal variations presented in theses façades, the periodic inspections that are recommended could also have the time span decreased.

4 CONCLUSIONS

Our results showed great temperature differences between the absorbances. The seasonality of the climate also was a determining factor in the degradation of the façades.

Temperature and thermal amplitude (ΔT) responses showed that the most critical incidents occurred on northern and western orientations, which may have a tendency to possess higher rates of degradation, which was already proven by previous studies. In Brasilia, the dry season presented higher values in the great majority of cases, when compared to the rainy season, both for surface temperature and ΔT, which may be the determinant factors for the evolution of façade degradation in these orientations; thus, to the dry season may be attributed the greatest responsibility for degradation.

The union of the studied parameters (absorbance and climatic factors like radiation, wind-driven rain and temperature) is shown as a determinant for degradation. Since façades with higher absorbances had the most critical values presented, for the west and the north orientations (in terms of temperature), and for both wind-driven rain and radiation, these façades had higher incidences. As such, the necessity of adaptation of material characteristics is evidenced and adaptation of the design phase, due to the natural environment.

As was proven, the software can be used as a tool in the design phase, during calculation of the service life of a building (indicating the façades most affected by the climate), and to assist in the implementation of maintenance actions. Furthermore, the results can be used as a way of comparing the degradation presented by the façades.

As recommendations for future papers, the application of this same methodology is suggested for other cities worldwide; and we suggest a more systematic evaluation, considering other possible sources of problems, such as: use, lack of maintenance, execution, etc. It is also suggested to do tests with other construction systems in hygrothermal simulation, such as with concrete, mortar and other coatings.

ACKNOWLEDGEMENTS

The authors would like to thank Fundação de Apoio à Pesquisa do Distrito Federal (FAP-DF), Centro Universitário UNIEURO, Instituto de Educação Superior de Brasília (IESB) and Instituto Federal de Goiás (IFG-Formosa).

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RETHINKING THE BUILDING ENVELOPE: BUILDING INTEGRATED ENERGY POSITIVE SOLUTIONS

JOANNA CLARKE[1], JOHN LITTLEWOOD[2], PAUL WILGEROTH[2] & PAUL JONES[1]
[1]SPECIFIC, Swansea University, Wales, UK
[2]Cardiff School of Art and Design, Cardiff, Wales, UK

ABSTRACT
This paper discusses information from a research project investigating a new approach to designing energy positive buildings that integrate renewable energy generation into the building fabric. Such buildings can help reduce energy consumption and associated carbon emissions, alleviating fuel poverty and lessening the need for costly grid upgrades. The main purpose of this study is to highlight the current status of the UK construction industry and the need for improvements, which have been documented over the years. Several enablers for the construction industry to change are identified, including collaborative procurement methods, building information modelling (BIM), innovation and energy positive buildings. The key findings from the review provide evidence that the energy positive solutions put forward in this research project, linking collaboration, innovation and buildings with reduced energy use and carbon emissions, could be used to improve the overall performance of the construction industry. This provides a good knowledge base for the next phase of the research, which includes interviews and workshops with construction industry stakeholders to further identify the challenges, benefits and drawbacks of the potential building integrated energy positive solutions. The combined body of information gleaned from this literature review, the feedback from construction industry stakeholders, and case studies of energy positive buildings designed by the first author, will be used to aid the development of the proposed outcomes of the research project, which will include a continuous improvement tool, the case studies themselves and the development of an innovation portal.
Keywords: energy positive, innovation in construction, collaborative procurement.

1 INTRODUCTION

The first author is undertaking research associated with her role at the SPECIFIC Innovation and Knowledge Centre (IKC), UK, in the context to their work on energy positive buildings [1]. Three energy positive building projects designed by the first author and one designed by others will be used as case studies in the research project, see Fig. 1 below.

This paper will examine existing literature on collaborative tools, techniques and procurement methods for the delivery of a sustainable built environment, including how innovation and change have been addressed in the construction industry to date (2018) and the challenges experienced. Challenges the project will address are focused around the need to reduce the amount of energy consumed by the built environment and the consequent carbon emissions that are harmful to the natural environment. The building and construction sector are responsible for approximately 30% of all global energy consumption and the associated greenhouse gases [2], suggesting a solution to address this is necessary and timely. Continuous improvement tools developed for construction and other industries will be subject to further investigations as part of the overall research project, to determine whether there is any evidence to suggest they could be used to encourage a more cohesive environment for the delivery of energy positive buildings. This work does not form part of this paper.

WIT Transactions on The Built Environment, Vol 183, © 2019 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ARC180141

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Figure 1: Case Studies – Active Pod, Active Classroom, Active Office and Active Homes.

2 THE NEED FOR CHANGE

The need for the UK construction industry to improve performance has been widely reported and two of the main reports on the state of the industry, "Constructing the Team" [3] and "Rethinking Construction" [4], both commissioned by the UK Government, are cited in many of the papers reviewed in this study, even those where research is non-UK focused [5]–[16], emphasising their significance to the industry.

Egan [4], who chaired the Construction Task Force set up by the then Deputy Prime Minister, John Prescott, in 1997, suggested the construction industry look to other industries, such as manufacturing in terms of what has driven them to achieve radical changes and better processes and identified some key drivers of change that have worked and are applicable to the construction industry. These include: Committed Leadership; A focus on the customer; Integrate the process and team around the product; A quality driven agenda; and Commitment to people (ibid). However, ten years later in 2009, little improvement to the industry had been made and another industry expert produced a report entitled "Never Waste a Good Crisis" [17], which found the suggested approach to apply manufacturing experience to an industry as different as construction was deemed unrealistic by the construction industry professionals questioned. Twenty years later, in 2018, the drivers suggested by Egan [4] are still relevant and not fully addressed.

Wolstenholme [17] further proposed that one of the greatest challenges to the industry was delivering a low carbon economy through the built environment. The energy positive case studies used in this research project (shown in Fig. 1 above) will demonstrate how this might be possible.

3 ENABLERS OF CHANGE

3.1 Collaborative procurement

Collaborative procurement is described as "…an effective way for more than one client, contractor, consultant or supplier to join together to procure work, services, materials or goods, share expertise, promote efficiency and deliver value for money savings in the delivery of a project…" [18].

The implications of procurement on the delivery of energy efficient buildings and the need to move away from cost-driven procurement methods is discussed by Alencastro et al. [19]. They discuss how, although Design and Build (D&B), for example, was established to encourage and enable better value for money, it is more often used to drive down costs, as also found by Eriksson [20]. Their research found that a collaborative method of procurement is essential to enable the inclusion of energy performance targets as a fundamental objective at an early stage in the project (ibid).

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A study of the Australian construction industry [10] discussed how a no-blame culture can enable collaboration and promote innovative thinking. Within the Australasian Project Alliance procurement form referred to in the study, a "no-blame" behavioural contract clause was added to demand behaviours that result in a collaborative culture change and beneficial innovation, with all stakeholders having equal responsibilities.

Lloyd-Walker et al. [10] state that Design and Construct contracts can aid the use of innovation to improve value for money. They also mention an increased popularity in partnering arrangements, although evidence from the UK construction industry in 2015 found only 5% of contracts used were Project Partnering Contract (PPC) 2000 and 3% Joint Contracts Tribunal-Constructing Excellence (JCT-CE) [21], the two main forms of UK partnering contracts. Lloyd-Walker et al. [10] cite Dulaimi et al. [22] who reference the Singapore Governments C21 Report, which found that fragmentation and lack of integration within the construction industry has reduced productivity and that "creativity, quality and work innovation needed to be rewarded in order to promote innovation". This is happening in the UK through schemes such as the Welsh Government Innovative Housing Programme [23], and Transforming Construction [24], both of which encourage innovative ways to improve construction and deliver better value for money for new buildings.

Kilinc et al. [25] also acknowledge D&B procurement as providing an opportunity to achieve innovation in the delivered project. Conversely, Eriksson [20] found that use of D&B contracts can hinder innovation due to the lack of joint problem solving between designers and contractors as the design is complete before the contractor is involved, resulting in a lack of holistic design and construction. This was not the case when delivering the energy positive case studies referred to in this project, where D&B aided the collaborative approach and use of innovative technologies, as described by Kilinc et al. [25].

Naoum and Egbu [26] review procurement methods in relation to innovation and technology, supply chain, lean construction, buildability, sustainability and value management. Their research concludes that the usual criteria used by clients when assessing tenders of time, cost and quality, are too simplistic for today's complex construction projects (ibid). However, in the first author's experience, these criteria are still the main factors determining procurement decisions. Naoum and Egbu [26] reference Ball and Fortune [5] who found that embracing sustainable construction will facilitate a change towards the use of partnering as a procurement process. After discussing how breaking the fragmented approach of the traditional route and encouraging cooperation through an integrated method of procurement to improve value of a project, Naoum and Egbu [26] conclude that, as clients and their project teams experience the benefits achieved through a more collaborative approach, a more integrated industry, where continuous improvement through team integration is seen as critical, will emerge (ibid). For the construction industry to embrace this, it needs to welcome "change" and allow innovative procurement methods to grow. The change needs to be mainly client-driven, with support from the rest of the project team (ibid). However, the Latham Report [3], advocating partnering and collaborative working, was written 24 years before 2018, and the uptake has been slow since this date. Challender et al. [8] suggest that the economic climate of austerity in 2013 significantly impacted on the trust element of collaborative procurement, which could explain the slow uptake. The perception that partnering is expensive has led to a return to competitive practices focusing on a short-term perspective of securing lowest price, but they suggest Building Information Modelling (BIM), as described in Section 4.2, could help revive collaborative working (ibid).

In conducting research into partnering arrangements and gaining contractor's views, Eriksson [20] found that clients and contractors viewed partnering positively, particularly for large complex projects with high uncertainty, and it worked well when a collaborative culture

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was created amongst the project team. Eriksson and Westerberg [27] had previously discussed the positive effect collaborative procurement has on project performance, including cost, time, quality, environmental impact, work environment and innovation, with client leadership, as found by Egan [4].

Ey et al. [9] expand on Eriksson and Westerberg's [27] research to investigate barriers and challenges of collaborative procurement which they state is about "striking organisational synergies within a construction project team to reduce barriers to innovation and facilitate a cooperative project delivery". The main human-related barriers found were trust, communication, understanding of collaborators, cultural differences and relationships, while the main commercial-related barrier was commercial pressures, specifically the complexities of the commercial and contractual frameworks required to support collaboration [9]. The study concludes by reporting that while collaborative procurement has the potential to address some of the inherent difficulties facing the construction industry, there are barriers and challenges to the success, which are difficult to address (ibid). The case studies used in this project aim to tackle these challenges and remove some of the barriers.

3.2 Building Information Modelling (BIM)

The concept of BIM was first discussed as far back as 1962 by Douglas C. Englebart [28] but became mainstreamed within the UK construction industry in 2011 to encourage collaborative working practices to deliver construction projects by getting people and information working together effectively and efficiently through defined processes and technology [29].

Shibeika and Harty [30] examine how one company adopted digital innovation. To do this, they use diffusion of innovations (DOI) theory, which examines how new ideas move through a social system, to investigate how the innovation could change a complex firm, also applicable to the wider industry. The authors begin by explaining the key role of BIM in aiding the development of the construction industry. They recognise the complexity of the construction industry, which can stifle the diffusion of new technologies and practices and also the fact that organisations within the construction industry are constantly faced with changes, as the industry evolves and with the varied nature of each individual building project (ibid), concurring with research by Loosemore and Richard [11] and Matinaro and Liu [31]. This can make it more difficult for momentous changes to be diffused throughout the industry, which is fast moving and involves many changing factors.

While procurement routes (such as partnering and frameworks) and systems (such as BIM) exist to enable collaboration in construction projects, research studied within this paper suggests it is easier to implement these on large projects. Edie.Insight [32] also found that sustainable development is more likely to be driven by larger-sized construction companies. However, 99% of UK construction contracting businesses are small or medium enterprises (SMEs), which is of significant concern to the industry [32]. In a survey carried out by Edie.Insight, respondents were asked to identify the three most significant sustainability investment areas for their organisation during 2017/18 – only 33.33% identified "sustainable product design/innovation", which suggests it is not high on their agenda, possibly since it is not always in their control and needs to be driven by the client (ibid). Alwan et al. [33] also suggest that the proportion of small firms (up to 59 employees) making up the industry is one of the cultural challenges to sustainability within the construction sector. A large proportion of responsibility for reducing negative qualities of the industry lie with small companies. The proportion of small companies also leads to a low level of investment in training, education, innovation and research, resulting in most building personnel having only basic knowledge

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of global consequences of construction waste, pollution and emissions (ibid). The first author has come across one example of a small UK practice of five full-time staff, Constructive Thinking, that utilises BIM effectively for collaborative working even on small projects [34].

3.3 Innovation

Whilst Egan [4] suggested the construction industry learns from the manufacturing industry, Salem et al. [35] cite the main features of the construction industry that differ from manufacturing as: on-site production; one-of-a-kind projects; and complexity; the combined effect of which is uncertainty throughout the whole project.

Shibeika and Harty [30] suggest that use of DOI theory is perhaps too linear to deal with the complexities of construction and look to the work of Peansupap and Walker [36], who suggest that change management and social network analysis may be more appropriate. DOI and the non-collaborative, blame culture, are considered by Ajayi et al. [37] when examining the cultural change needed in the UK construction industry to deal with reducing waste to landfill. Ajayi et al. [37] found that organisational culture determines employees' readiness for innovation as well as their strategy and approach to innovation. Difficulties of adopting innovation in construction stem from the complex nature of the industry and its reliance on casual employment of labour force, i.e. it is not as stable as the manufacturing industry. The fact that designers and contractors usually work independent of one another adds to the difficulties, although this is addressed through collaborative working, enabled through partnering and frameworks (ibid), as illustrated by the case studies forming one of the outputs of this research project. Matinaro and Liu [31] discuss how a cultural transition to more innovative thinking in the construction industry can impact on sustainability, proposing that leadership is required to develop a culture towards change as also suggested by Kotter [38]. This is further discussed by Mousa [39] who uses Kotter's [38] eight-step model for change to consider an approach to transforming to sustainable construction in a developing country. Costs are recognised as a major barrier to the widespread use of sustainable materials due to higher upfront capital costs and a disregard for life cycle and performance, which is also described in the research work of Darko and Chan [40].

Matinaro and Liu [31] recognise that challenges of innovation in the construction industry are in part due to the diverse and multi-levelled nature of the industry and the fact that it is a project-based industry, concurring with Ajayi et al. [37]. Whilst the industry is reported as being non-collaborative and lacking innovation, it naturally works in a collaborative way, necessary to deliver buildings. However, the authors state that innovation is stifled by "ineffective leadership, ingrained cultures, outdated technologies, poor logistics and lack of using solutions such as BIM" effectively. To enable change, "sustainable development must be seen as an opportunity for the construction industry, not as a cost." Matinaro and Liu [31] state that innovation management is not seen as important to construction companies because of practical and result-orientated ways of thinking, their main aim being to deliver buildings to client's briefs, within budget and to an agreed programme. An innovative organisational culture includes features such as knowledge sharing, tolerance of mistakes (viewed as learning opportunities) and good collaboration abilities, none of which are perceived strengths of the construction industry (ibid).

Loosemore and Richard [11] found that the economic dilemma of innovation in the construction industry stems from clients, who are unable and unwilling to provide scope and time in projects for innovation to happen. Reasons included: internal governance constraints; a lack of tools to value innovation in bids; a poor understanding of how built assets contribute to core business objectives and a narrow understanding of their central role in driving

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innovation. Therefore, innovation only tends to occur on large projects or with clients who procure multiple buildings. Most of the industry work with clients who procure buildings rarely, who want the lowest price for their investment and who do not recognise the building as a key long-term asset. Their research suggests that clients need to drive innovation and allow the construction industry to innovate, but the construction industry needs to educate clients to know this, to be aware of their role. The authors recognise that further research could explore the reasons why clients may find this difficult or be reluctant to adopt their recommendations (ibid). They refer to the McKell Institute Report into productivity in the Australian industry, written in 2012, which declares that firms must "innovate or perish" [41], a sentiment echoed by Farmer [42] in "Modernise or Die", recognising that the construction industry is always adapting and a large amount of innovation occurs, but the nature of the industry makes it challenging to make bold, obvious innovation within the industry due to its complexities [11].

3.4 The move towards energy positive buildings

In 1983 "Our Common Future" highlighted the important role buildings have to play in saving energy, stating that a low energy path is the best way to a sustainable future [43]. Consequently, there is a large amount of literature on "green" or sustainable buildings, some of which is summarised in this section.

Darko et al. [44] study drivers for implementing green building technologies. They find the top five drivers as being: energy-efficiency; reduced environmental impact; water-efficiency; occupants' health, comfort and satisfaction; and company image. Darko et al. [45] build on this initial research by undertaking a detailed literature review. Here, they identify "Government regulations and policies" as being the top driver. However, in a review of the barriers to green building adoption, Darko and Chan [40] found lack of green building codes and regulations is also seen as one of the barriers, although lack of information, cost, lack of incentives, lack of interest and demand, are also barriers listed.

Brejnrod et al. [46] describe a method to calculate the "absolute sustainability' of buildings, meaning that a buildings annual environmental burden is less than its share of the earth carrying capacity. One of the ways to reduce energy consumption was identified as reducing the impact intensity per energy unit, achieved by using renewable energy generation locally and by the public energy supply, which aligns with the energy positive case studies used in this research project. Meanwhile, Kosai and Tan [47] present a study of zero energy buildings from an energy trilemma perspective, finding that on-grid zero energy buildings with renewable energy delivered a better performance than off-grid zero energy buildings – also aligning with energy positive buildings developed as part of this research project. Roaf and Nichol [48] advocate a change in design thinking back to more environmentally adaptive design of buildings. The authors state that consideration of building performance by architects at an early stage in the design process does not happen in many modern buildings.

The research of Attia [49] is dominated by ideas of regenerative design, cradle to cradle design and biomimicry, for environmentally effective sustainable buildings. An integrated design process and design-bid-build procurement are key to delivering low-energy buildings at zero or little extra cost, whereas the traditional, linear approach leads to missed opportunities (ibid). Rasekh and McCarthy [50] showed that to be sustainable, it is essential to be innovative. The main challenges they found were capital cost uplift, knowledge about sustainable buildings, and the necessity for early engagement of contractors, echoing findings from other research described in this paper.

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While the research examined used different terminologies and focused on slightly different aspects of "green" buildings, the main thread is the same – that there is a need to reduce the amount of energy used by the built environment but, in order to address this, it is critical to understand the challenges and drivers for change.

4 DISCUSSION

The literature examined above, clearly points to a need for a different approach to enable collaboration and innovation in construction, to deliver energy positive buildings, highlighting many challenges the construction industry faces. A collaborative approach was shown to be effective on large, complex projects, but these are still highlighted as pilot examples and not the norm. Nor have they been shown to work on smaller projects. It is timely to examine this now as it is twenty years since Rethinking Construction [4] and the industry is fast approaching the targets set out in Construction 2025 [51]. The need for an innovative solution is becoming ever more pressing and there is a gap in knowledge around this, as the literature illustrates.

The literature review has helped to refine the aims and objectives of the research project and provided evidence that this research is needed and is appropriate at this moment in time (2018). The main aim of the project is to investigate a new approach to procuring energy positive buildings, that integrate renewable energy generation into the building fabric to reduce the energy consumption of buildings and associated carbon emissions while improving user comfort within buildings.

Several common factors that affect the ability for the construction industry to work collaboratively were identified in the literature. These include: trust, cost, fragmented nature, risk, clients, culture, traditional procurement, time, funding, size of firms, communication, technology, lack of information and regulations; all of which need to be addressed to improve the overall performance of the industry and to enable innovation in construction, particularly to enable energy positive buildings. The first author proposes that energy positive buildings, such as those designed by the first author (see Fig. 1 above), which include innovative elements and are delivered in a collaborative way, could address many of the challenges facing the construction industry, as well as global challenges to reduce energy use in the built environment.

5 CONCLUSIONS

From the literature examined, there is strong evidence of links between collaboration, innovation and energy positive buildings, which address global environmental issues, suggesting that creating energy positive buildings in a collaborative way using innovative techniques and technologies could help transform construction.

Some research has explored the use of manufacturing techniques for lean construction, but there is room for further research in this area to aid the use of innovative sustainable techniques and technologies in construction. Whereas the challenges, drivers and barriers to innovation in construction are well documented, no clear solution has been identified within the literature. While collaborative working and innovation are identified as necessary to enable an energy efficient built environment and that such an environment is essential to addressing environmental, economic and social concerns, perceived costs, lack of knowledge and procurement methods appear to be the main barriers. There is a belief that enabling delivery of energy positive buildings through innovation and a collaborative process should be client-led. The way the client deals with procurement affects the entire construction process, including the degree of integration and cooperation between the project team [27].

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These findings suggest the gap in knowledge is in finding a way to successfully implement collaborative working and innovation in one-off projects and to educate clients in how this approach could benefit them in the long term, providing a strong evidence base for the first author's research project. The case studies shown in Fig. 1 will aid this education process, through engagement with construction industry stakeholders. Further work will describe the next stage of this project which involves collecting data on the case studies.

ACKNOWLEDGEMENTS

The first author wishes to acknowledge support of the European Regional Development Fund through the Welsh Government in addition to Innovate UK and EPSRC, all of whom contribute funding to SPECIFIC. She would also like to thank her supervisors for their time and efforts in assisting the writing of this paper.

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WIT*PRESS* ...for scientists by scientists

Sustainable Development and Planning X

Edited by: ***G. PASSERINI****, Marche Polytechnic University, Italy and* **N. MARCHETTINI***, University of Siena, Italy*

This volume contains research from the 10th International Conference on Sustainable Development and Planning. The papers included in this volume form a collection of research from academics, policy makers, practitioners and other stakeholders from across the globe who discuss the latest advances in the field.

Problems related to development and planning, which affect rural and urban areas, are present in all regions of the world. Accelerated urbanisation has resulted in deterioration of the environment and loss of quality of life. Urban development can also aggravate problems faced by rural areas such as forests, mountain regions and coastal areas, amongst many others. Taking into consideration the interaction between different regions and developing new methodologies for monitoring, planning and implementation of novel strategies can offer solutions for mitigating environmental pollution and non-sustainable use of available resources.

Energy saving and eco-friendly building approaches have become an important part of modern development, which places special emphasis on resource optimisation. Planning has a key role to play in ensuring that these solutions as well as new materials and processes are incorporated in the most efficient manner.

The application of new academic findings to planning and development strategies, assessment tools and decision-making processes are all covered in this book.

WIT Transactions on the Built Environment, Vol 179
ISBN: 978-1-78466-291-2 eISBN: 978-1-78466-292-9
Published 2018 / 1024pp

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