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International Sustainable Ecological Engineering Design for Society (SEEDS) Conference 2018

Conference Proceedings

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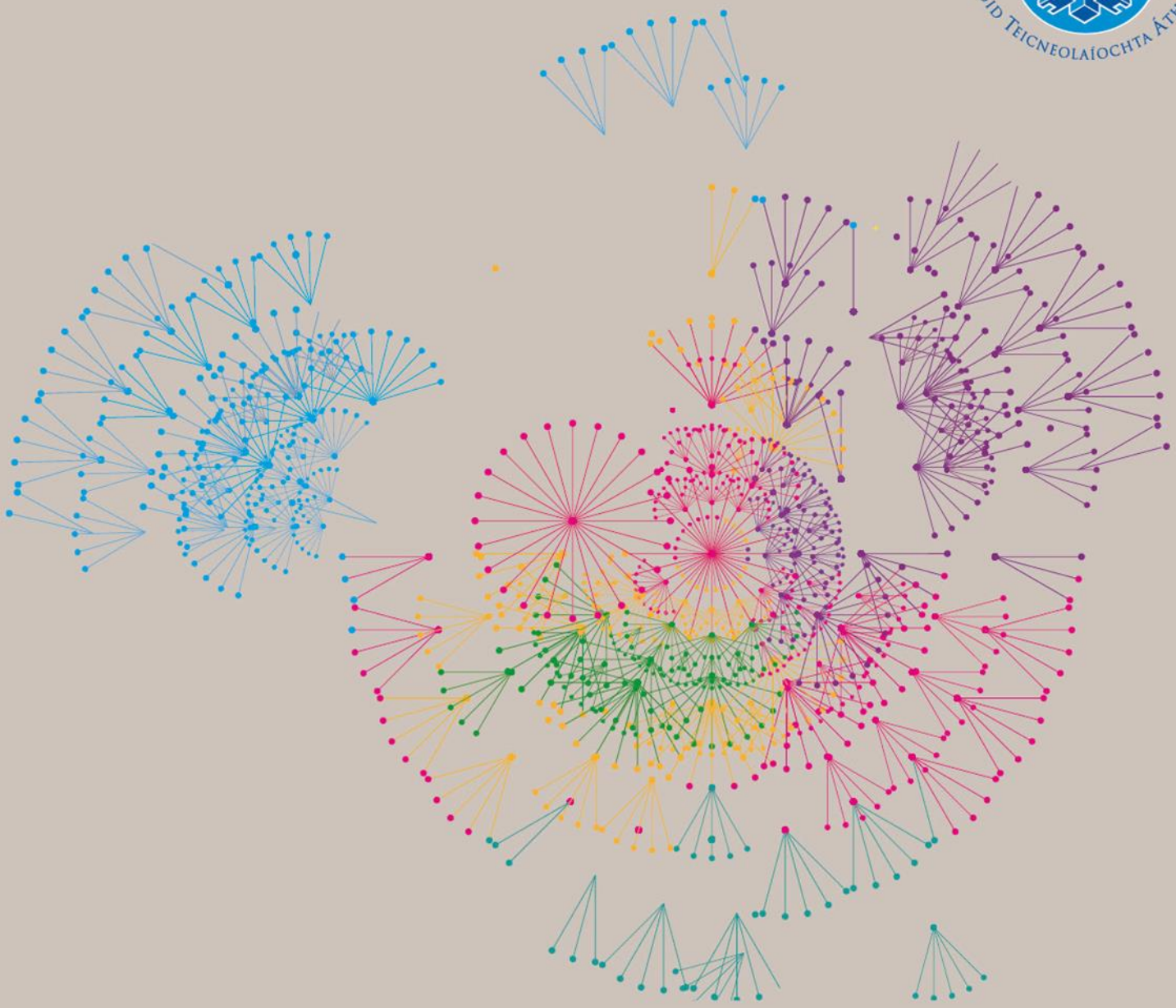

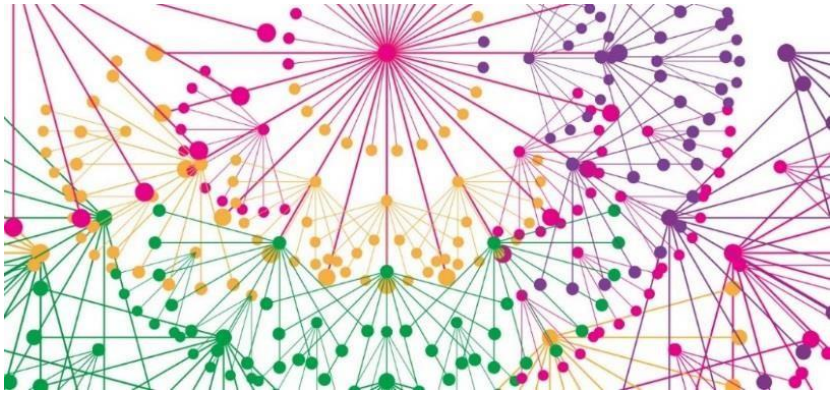

Sustainable Ecological Engineering Design for Society (SEEDS)

Conference Proceedings from the Fourth International SEEDS Conference

Conference Chairs

Professor Lloyd Scott

Professor Chris Gorse

6th and 7th September 2018

Dublin Institute of Technology

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CONFERENCE PROCEEDINGS FROM THE FOURTH INTERNATIONAL SEEDS CONFERENCE 2018

Enabling Sustainability – Re-engaging stakeholders

Grangegorman Campus, Dublin Institute of Technology, Ireland – 6th and 7th September 2018

The built environment has a greater impact on natural resources and produces more waste than any other industry. However, beyond the green rhetoric research is being applied on the ground to address the balance between the built and natural environment. The International SEEDS Conference, now in its 4th year, brings together experts from around the world focusing on the changes that are taking place and the benefits or consequences that are being predicted and measured regarding the built environment's impacts. As well as addressing technical issues, measuring energy efficiency and modelling energy performance, emphasis is placed on the health and wellbeing of the users of spaces occupied and enclosed. Understanding how buildings and spaces are designed and nurtured to obtain the optimal outcome is the focus of discussion and debate. This holistic approach draws together the research themes of energy, building performance and physics while placing health, wellbeing and ecology at the heart of the conference.

Through research and proven practice, the aim of the SEEDS conference is to foster ideas on how to reduce negative impacts on the environment while providing for the health and wellbeing of the society. The professions and fields of research required to ensure buildings meet user demands and provide healthy enclosures are many and diverse. The SEEDS conference addresses the interdependence of people, the built and natural environments, and recognises the interdisciplinary and international themes required to assemble the knowledge required for positive change.

The 4 main conference themes

Energy and Buildings	Environment
Design for the 21st century	Sustainability education

Conference Sub Themes

- Protecting nature and the natural environment
- Building and environment design
- Energy efficient modelling, simulation and BIM
- Integrating urban and natural environment
- Building performance, analysis and evaluation

- Thermal comfort, air quality and overheating
- Green spaces, enclosures and buildings
- Green technologies and IT
- Renewable energy
- Energy flexible buildings
- Energy behaviour and lifestyle
- Dampness, water damage and flooding
- Building surveys, thermography, building pathology
- Water and air quality
- Education & training
- Planning and sculpturing positive change
- Reducing consumption and waste
- Sustainability, ethics and responsibility
- Occupant behavioural change
- Community building and master planning
- Health benefits of alternative and natural materials
- Urban heat island and mitigation
- Building resilience
- Sustainable cities
- Zero energy and energy plus buildings
- Local producers and urban environments, edible
- Trees and green city landscape
- Edible urban landscape
- Biomimicry and biophilic design

Conference Chairs

Professor Lloyd Scott
Professor Chris Gorse

Preface

Sustainability and the associated issues are expected to be considered at a very integrative and holistic way in addressing the three key pillars of sustainable development, namely the environment, technology and the associated economics, while taking into consideration the macro and micro contexts. This event provides a platform to discuss the recognized and important problems affecting sustainable built environment. Specialized practitioners and researchers have the opportunity to share their research and views in a range of topic related to Sustainability, Engineering, Ecology and Design for Society. Interested policy makers, researchers, practitioners and educators whose interest lies in the subjects of sustainability, design, engineering, energy and education will be more effective if they integrate their efforts in order to share and influence governments, the greater society at large and academic institutions in this topical areas. This conference provides the opportunity for researchers and practitioners to share emerging research, best practice, develop and promote a network of experts who are passionate about a sustainable future.

SEEDS 2018

Greetings and a warm Dublin welcome! It has been our honour to chair this 4th Sustainable, Ecological, Engineering, Design for Society (SEEDS) Conference. It is my pleasure to welcome you to the wonderful city of Dublin; a vibrant cosmopolitan city that is home to three universities, soon to be four when, in January 2019, DIT, ITB and ITT will merge to become Ireland's first technological university, the Technological University Dublin. Dublin is home to some of the most enduring writers in the English language, and retains its prestige as one of the vibrant literary capitals of Europe, and its tradition is proudly maintained in museums, walking-tours, and heritage sites of all kinds. Of course the tradition of music is alive and well too!

It is a special pleasure to welcome you to the SEEDS conference at the fast developing Grangegorman campus of Dublin Institute of Technology. This is the fourth SEEDS conference but the first to take place outside of the UK and so I would particularly like to extend a warm welcome to Dublin. The conference has grown over the last four years and as well as being associated with it I have been privileged to take on the role of conference chair. While on a day-to-day basis we tend to focus on our own distinct areas of research, an occasion like SEEDs provides the opportunity to reflect on where our work fits in to the complex environment in which we exist.

Climate change, resource efficiency, greater demands on social care, urbanisation and immigration, an ageing infrastructure, the need to stimulate economic growth, as well as constrained budgets: these are challenges faced by society as a whole. An innovative and growing built environment is a crucial component for tackling these issues that confront us. There are increasing global concerns related to climate change and sustainability in the built environment. Buildings contribute some of the largest environmental impacts. For instance, in many developed countries nearly half of total carbon dioxide emissions come from energy use in buildings, more than half of all public water supply in the developed world is for household use, building construction and demolition waste still accounts for 32% of all waste, with 13% of products delivered to construction sites being sent directly to landfill without being utilised. The emergence from the current economic recession, have challenged the industry to explore effective ways of achieving sustainability. There is both a need and an opportunity for research in the disciplines relating to sustainability in the built environment. Research that can lead to, for instance, a better understanding of the concept of sustainability and the measurement and management of sustainable construction etc.

The contributions to the four themed areas of Energy and Buildings, Environment, Design for the 21st century and Sustainability Education have been impressively positive. We have been particularly driven to create a unique programme that truly represents the SEEDS mission: to collaborate and to share! To collaborate as academic peers, and to collaborate with our industry partners.

It is with great excitement then that we will see some 85 conference attendees from more than 50 different countries come and exchange ideas, research and practices both formally in the parallel sessions, and informally over coffee, lunch, dinner, or drinks. Just like the city itself, this

conference series is diverse and exciting, and promises the opportunity to expand professional networks and research partnerships; engage in new, and consolidate old, friendships; and to be challenged and inspired.

The past few months have been an exciting time for the organising committee, as we have collaborated on a number of stimulating interdisciplinary projects and initiatives. What is more, we have recently launched Twitter (SEEDSDUBLIN 2018) and Instagram (SeedsDublin 2018) accounts for you to share your experiences – please join in and get involved.

I would like to thank the members of the SEEDS Scientific Review Group, the conference Organising Committee members, our keynote and featured speakers, but most notably the Dublin Institute of Technology, and Leeds Sustainability Institute, Leeds Beckett University. Last, but not least, I would like to thank the delegates from around the world, who make this conference possible, and this organisation come alive.

This SEEDS conference is focused on sustainability in the built environment with the purpose of helping researchers to develop the area and highlight some of the research approaches being taken. The themed emphasis includes the five papers being presented (and another two that were submitted but could not be delivered at the workshop for a variety of reasons). All of these papers, together, present a useful insight into the current research in addressing sustainable, ecological, engineering design for the society in which we live. It is interesting to see the diversity of research covered in this two-day gathering. Possibly, such diversity is a reflection of the wide-ranging attempts to define sustainability and measure sustainable development. However, the themes of Energy and Buildings, Environment, Design for the 21st century and Sustainability Education that are embedded in the papers of these proceedings will certainly be relevant to future debate in the wider community. We are particularly pleased to have such a great response in the themed area of Sustainability Education.

We look forward to two eventful days where discourse, sharing and building up new relationships in charting a 'sustainable' future is the imperative! We have so much to learn from each other and I am confident that you will come away from the conference inspired!

Have a wonderful time in Dublin, enjoy the conference, and enjoy the discourse and camaraderie of the SEEDS community.

Professor Lloyd Scott
Professor Chris Gorse

SEEDS conference chairs

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Sustainability

SUSTAINABLE CITIES AND ITS OPPORTUNITIES IN THE NIGER DELTA REGION OF NIGERIA

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Keywords: Migration, urbanization, sustainable cities, opportunities of sustainable cities.

Abstract

Presently, more than half the world's population lives in cities, and it is projected that 6 in 10 people will be urban dwellers by 2030; thus, making urbanization a defining feature of the 21st century. It becomes important to make these rapidly urbanizing cities like the ones in the Niger Delta region of Nigeria sustainable for human settlement and find out the opportunities that sustainable cities present. The Niger Delta region is an oil producing region in Nigeria. Following the oil exploratory activities in this region, migration-induced urbanization has been rapid and without development, resulting to diverse challenges. Considerable literature has explored these challenges and its impacts on sustainable cities. However, limited literature explores what characterises a sustainable city and the opportunities it presents. This is important because substantial studies have shown that the wealth and economic success of Nigeria comes from the region, yet it has continued to suffer marginalization and neglect from the government and multi-national oil corporations, hence, rapid urbanisation without development. Unfortunately, there has been little or no steps to ensure the sustainability of its rapidly growing cities. This is because to harness the opportunities of cities, the sustainability of such cities is of paramount importance and should be a priority. Therefore, the aim of this study is to find out what is a sustainable city and what makes a city sustainable? To address this question, this study will critically review and analysis relevant academic literature as well as papers and reports produced by the United Nations on World cities.

INTRODUCTION

The rate of the urbanisation of countries in recent years is phenomenal and unprecedented, such that has never been witnessed in the history of man. Davis Kingsley, a renowned demographer predicted the arrival of the explosion of urbanisation on a world scale in the year 1955 (Brenner & Schmid 2014). Importantly, Davis gave this prediction strictly on empirical basis when in his work titled, 'origin and growth of urbanisation in the World' he made this observation;

"almost any technological advance from now on is likely to contribute more to the centrifugal than to the centripetal tendency. It may turn out that urbanization in the sense of emptying the countryside and concentrating huge numbers in little space will reverse itself-not, however, in the direction of returning people to the farm but rather in that of spreading them more evenly over the land for purposes of residence and industrial work. 'Rurality' would have disappeared, leaving only a new kind of urban existence" (Davis 1955, p. 437).

A trace of the trends and rates of urbanisation over the years starting from the 1950s when Davis gave this prediction will show at a glance a clear manifestation of Davis's prediction – meaning that the world has been witnessing an explosive rate of urbanisation in recent times. For instance, in 1950, about 30 per cent of the world population resided in the urban centres, this rose to about 54 per cent in 2014, and 54.5 per cent in 2016 (United Nations, 2014; 2015 & 2016). According to these records, urban areas are projected to house 60 per cent of people globally by 2030, and by 2050, 66 per cent of the world's population is projected to be urban. Arguably, this is explosive and if it continues like this in the near future, it will get to the point when urbanity will take over rurality (in Davis's terms see Davis, 1955). Indeed, this rate of urbanisation depicts the prevalent urban age thesis - an age when more than fifty percent of the world's population live in cities (Friedmann 2006, Bloom, Canning & Fink 2008, Chen, Zhang, Liu & Zhang 2014, UN-HABITAT 2006).

While there is consensus among scholars that the cities are growing rapidly, there is no consensus as to what drives this growth. There is a historical argument that economic development drives the growth of cities/urbanisation, other arguments centres on the fact that economic development is not an indispensable driver of the growth of cities (Fox, 2016). Recently, there is a shift in this debate where scholars seek to find out whether urbanisation drives development or whether cities are engines of growth (Potts, 2016). *Moreover, the UN-Habitat, 2016, p. 4) further confirms that "cities create wealth, generate employment and drive human progress by harnessing the forces of agglomeration and industrialization. Also, the New Urban Age Agenda emphasizes that there is the need* for countries to take advantage of the opportunities of urbanisation/cities for economic development (see The New Urban Age Agenda, UN-Habitat, 2017, p. 3). It is arguable however, that the more sustainable cities are, the more opportunities they present for development, although these opportunities are not clear yet. Therefore, this study seeks to contribute to the latter debate by conducting a thorough literature to find out what it means for a city to be sustainable and arena for diverse opportunities.

That notwithstanding, it is important to point out that the staggering pace of the growth of the population of the cities of the world today calls for drastic measures. These measures should be geared towards making these cities sustainable because this will help to increase opportunities. This is because the more cities grow, the more it becomes important to make them sustainable/habitable while taking urgent measures to develop it further. So, the aim of this research is to evaluate what it means for a city to be sustainable and to explore the opportunities that are available in a city for sustainable development. Therefore, this study seeks answer to the question below;

1. *What is a sustainable city and what makes a city sustainable?*

In order to answer these questions, the study will start with a historical perspective on the Niger Delta of Nigeria. The methodology employed in the research will be expatiated. This will be followed by a review of literature on the concept of migration, leading to the discussion of urbanisation. Further to this, sustainable cities and its opportunities. Then the discussion of the findings which will help to draw conclusion from the study.

The Niger Delta Region of Nigeria: A Historical Perspective

Nigeria is one of the oil-rich developing countries of the world, made up of 36 states and capital. However, its oil resource was discovered in about 9 states namely; Abia, Akwa-Ibom, Anambra, Bayelsa, Cross River, Delta, Edo, Imo and Ondo. Prior to the discovery of oil, Niger Delta region like every other states in Nigeria was predominantly rural and agricultural, majorly farming and fishing. According to Okonjo-Iweala (2012), during the pre-oil period, agriculture employed about 70% of the population of the youths with about 80% of the people resident in the rural areas. However, the discovery of oil changed a lot of things in the region. The Petroleum-rich region that has been at the centre of National and International controversy over issues of mass migration, pollution, corruption and human rights violation, cities that lacks sustainability readily comes to mind whenever the name, "Niger Delta" is mentioned. Niger Delta may be a geographical location, but it is now a region defined more by oil-induced rapid urbanisation without development, rather than a history and territory populated by people. Besides the rapid urbanisation without development occurring in the region, the region is plagued by such challenges as oil spills, gas flaring and armed conflicts. However, this research centres on the sustainability of the migration-induced rapid growing cities in the region. This will lead to the discussion of the concept of migration, albeit, in a brief.

THE CONCEPT OF MIGRATION

Historically, people have continued to move and established settlements from one area to the other, thus, migration is not a recent phenomenon (Abbass, 2012). In most developing countries, this movement of people from one place to the other started basically as ruralrural migration, because most of these countries were predominantly rural and agrarian.

Mberu (2005), rightly pointed out that excluding the periodic and seasonal migration in subSaharan Africa, rural–rural movement is the most significant type of internal migration. Over time, the pattern of migration in most of these developing countries changed from mostly rural-rural to rural-urban, urban-urban and urban-rural and these recently represents the critical aspect of the patterns of migration dominant in some of these countries like Nigeria and its Niger Delta region (Oyeniyi, 2013; Bloch et al., 2015). Writing on rural-urban migration, Mberu (2005) states that rural-urban migration whether temporal or permanent is the most substantial form of movement for long-term spatial redistribution in subSaharan Africa. Therefore, in this study, rural-urban migration will be seen as one of the primary driver of the population growth in the cities of most developing countries like Nigeria (case study).

Lee (1966, p. 49), defined migration as a "permanent or semi-permanent change of residence". Although, this definition is far from being recent, with it is easy to understand that migration can be temporal (long term, short term, seasonal and circular) or permanent. However, the definition of migration as given by Lee, does not specify whether this change of residence is through rural-rural, rural-urban, urban-rural and urban-urban migration, which is the critical aspect of migration in countries in Africa (Oyeniyi, 2013; Bloch et al., 2015). This specification is important because it is possible for someone to change residence by migrating from one rural area to the other (rural-rural migration), some others can migrate from one urban centre to the others (urban-urban migration), and some others can migrate from urban centres to the rural

areas (urban-rural migration). For instance, Potts (2012) analysed the 1990 census of Zambia and argue that the urban population of the Copper belt towns was declining in size relative to the national population because its urban-rural migration exceeded its rural-urban migration.

Another definition of migration was the one given by Boyle, Halfacree & Robinson (2014). According to them, migration includes international flows of large numbers of refugees stimulated by wars, famine or political unrest (political reasons). Also, adults moving between regions in search of employment (economic reasons). It equally includes middleaged professionals migrating back to the land in their search for rural retreat (socio-cultural reasons -urban-rural). This definition shows the different reasons why people move. It also shows some of the different trajectories of movement, for instance, such movement as rural-urban, urban-urban, urban-rural can be deduced from the definition of migration given by Boyle, Halfacree & Robinson. Importantly, the definition also captures forced migration which are often neglected in the definition of urbanisation. Another aspect of migration that usually takes place in some regions that this definition captured is international migration –a situation where out-migrants from rural areas no longer hope to move to cities within their own countries instead they prefer to migrate to outside countries. This aspect of migration has been consistent in sub-Saharan African countries like Nigeria. For instance, research conducted in Francophone West Africa shows that many rural out-migrants seek to move straight to overseas destinations, mainly to Europe instead of moving from one city to the other within their countries (Potts, 2012). In fact, the description of migration given as by Boyle, Halfacree & Robinson is elaborate and encompassing, it clearly conveys the information that there is both forced and unforced migration. However, in some countries, not all forced migrants are refugees, some are even neglected to their fate, a situation that requires attention. In short, in defining migration, it is advisable to differentiate between forced and unforced migration, what drives it as well as the trajectories of movement to broaden the understanding of its meaning. Therefore, in this study, migration will be seen as the movement of people who are either pushed (forced) from the rural areas to cities or pulled (unforced) to urban centres due to oil-related factors.

It is needful to state that migration can be classified as voluntary and involuntary migration (Posel, 2002, p. 1), forced and unforced (Harvey, 1996), and expulsion (Sassen, 2013). While forced can in most cases be as a result of and environmental crises, political situation and socio-cultural issues, unforced can be response to economic pressure (McDonald, 2000; Rakodi, 2002b, 2002a). David Harvey pointed out that forced migration is the most potent and unstoppable facilitating factor to urban population growth in the world today (Harvey, 1996, p. 49). No wonder, Sassen (2013) used 'expulsion' which is a more powerful term to describe forced migration. According to Sassen (2013), forced migration arises when people are forcibly displaced or expelled from their homes leaving them with no shelter and food which are the necessities of life. Thus, leaving them with no other option than to migrate to other safe places to at least find shelter and food. This means that not all migration is voluntary, and not all migration is involuntary. When it comes to forced migration, factors such as war and conflict contributes to the displacement of people in some of these countries causing them to migrate unwillingly to the cities. With this, one can conclude that like urbanisation, migration is a continuum. The primary concern in this study centres on the aspect of migration that affects the rate of urbanisation that is, rural-urban migration to understand what pull and push people into the cities.

Rural-urban migration resonates even more in contemporary research on urbanisation due to its importance. Although the speed of rural-urban migration may have slowed down in some countries as identified by Potts (2012), there are developing countries in Africa like Nigeria whose rate of rural-urban migration has continued to be rapid. Lall, Harris & Shalizi (2006, p. 3) citing Brockerhoff (1995) argue that migration from rural areas accounted for at least half of all urban growth in Africa during the 1960s and 1970s and about 25 percent of urban growth in the 1980s and 1990s. Lall & Selod (2006, p. 3), in their World Bank Policy Research Working Paper, contended that the migration of labour from rural to urban areas is an integral part of the urbanisation process in developing countries. As a result of this, they pointed towards the "classic pull/push framework" to address the burning issues of what actually "push" rural dwellers to the cities and what "pulls" them.

The Push and Pull Framework of Migration

According to Clemens & Pritchett (2008), the considerable differences in income and living standards between places, as well as the general perception that migrant households are better off than non-migrant households, act as incentives for people to move to the cities. In Nigeria, in an average, one family has at least one migrant family member, through whose money remittances, their families can pay bills and procure critical medical needs. According to Lall & Selod (2006, p. 3), the rate of migration is determined by the rate of those factors that "pull" rural dwellers to the cities as well as the forces that "push" them to the cities. To Brueckner et al., (2014, p. 4) economic prospects - better economic opportunities in cities is a critical factor in migration. They also argue that agglomeration economies are a significant pull factor, that it often provides the primary motivation for internal migration. Brueckner et al., continued by stating that people are also pushed off their land by severe declines in agriculture, by the pressures of population growth, and by environmental changes that make cultivation no longer viable. Historically, droughts, they conclude, have had sudden and prolonged impacts on the population distribution in developing countries, particularly in sub-Saharan Africa and South Asia.

Further to this, researchers such as Black et al., (2006) and Kwankye et al., (2009) affirm that the critical pull factor of rural-urban migration in the developing world are financial considerations. According to them, it also includes employment opportunities, healthcare provision, infrastructure and other prospects for personal achievement and progress in the more developed urban centres, which are severely lacking in the countryside. With this, migrants continue to migrate to these cities in mass even if some of them cannot fit into the formal employment in cities due to lack of academic qualifications and the lack of adequate employment opportunities, the informal sector (for example, retail, construction, and agricultural sectors that require the unskilled labour market for survival) offer ready employment prospects for some of the migrants. This makes economic, socio-cultural and political factors to feed the pull and push framework of migration. However, the measures at which each of these factors pulls and pushes people to the cities differs, meaning that it may not be advisable to assume that one factor contributes higher than the others. Drawing such conclusion will require elaborate collection of data from the migrants, asking them why they move to cities, this will help to gather whether their movement is related to economic, political, social or even cultural reasons.

To add to this debate, Kainth (2009) contends that migration is a global phenomenon and what constitutes its push and pull frame are social and cultural factors and not economic considerations alone. Further to this, Akokpari (2000) argues that migration, whether voluntary or forced, intra-state or interstate is both an effect and cause of the political and economic conditions of the sub-Saharan African political dispositions. Akokpari further advanced that the political and economic factors that are often cited as the pull and push factors in migration in these countries result from the indecisiveness of the government in addressing critical economic, political, population and environmental issues. Contrarily to these suggestions, Potts (2012) affirms that migration is volatile and highly sensitive to economic signals. However, this point envelopes the push and pull factors under the umbrella of economic reasons alone, thus, an over-generation of ideas. As regards the migration in the oil rich Nigeria, Odularo (2008) argues that the new oil wealth, the concurrent decline of other economic sectors, and a lurch toward a statist economic model fuelled massive migration which in turn results to rapid urbanisation. Based on the following arguments, we argue that migration is fuelled by complex factors which include economic, social, political, environmental and religious factors. This means that on general basis, it is precaution not to tie the push and pull factors of migration on a single factor at the expense of the others. However, it can be said that what constitute as a major push and pull factor of migration in one country may differ from the other. In all, migration especially forced migration can be a prominent cause of rapid urbanisation in most countries (see Harvey, 1996). This is will lead to the discussion of the term, urbanisation.

THE CONCEPT OF URBANISATION

Parnell & Walawege (2011), indicated that there are two unmistakeable related meanings of the English term 'urbanisation' that are used rather confusedly. Firstly, urbanisation as the movement of people from the countryside to city see also (Higgins 2011). Secondly, urbanisation as the proportion of the national population of a country that live in urban rather than rural areas. On a random basis, the definitions of urbanisation from at least the year 1955 to 2015 provides evidence to this. For example, urbanisation has been defined as a situation where a sizable proportion of a country's population lives in cities (Davis 1955), as the increase of the urban population as compared with the rural one (Roberts 1978, p. 9); a transformation from a rural to an industrial way of living (Firman, Kombaitan & Pradono 2007), the increasing share of the population living in urban settlements (Stage, Stage & Mcgranahan 2010); the percentage of persons residing in an urban area which is accompanied by the migration of labour force from the rural sector to the urban sector (Babanyara, Saleh et al. 2010). Moreover, (Potts 2012) defined urbanisation as a demographic process whereby an increasing share of the national population lives within urban settlements. Writing in the year 2015 on the urban expansion of Nigeria, (Bloch et al. 2015, p. 4), defined urbanisation as an increase in the proportion of a country or region's population living in urban settlements. The various definitions of urbanisation as stated here confirm the fact that there is a kind of consensus amongst scholars that urbanisation depicts an increase in the total number of people residing in the cities. This is agreeable in this study. However, there is no agreement on the meaning of the term urban, for it has been difficult to arrive at an exact meaning of the term. As such, it

becomes necessary to discuss some of the meanings of the term to enable us to take a stand on which definition is more relevant in this study.

The Term Urban

In the study of urbanisation, there is substantial misperception or debate with regards to the term urban. As far back as in the 1960s, Macura indicated that there appear to be about thirty different definitions of the term, urban, yet none seems explicit to address this challenge of a lack of precise definition (Macura, 1961). This lack of exact meaning of the word is what Brenner (2013, p. 89-90), sees as a new challenge in urban studies. Geographers who are space-oriented defined urban as an area where there is the concentration of a specific population. Sociologists and anthropologists, on the other hand, associates the meaning of urban with human behaviour (Tettey, 2005). Unlike geographers, sociologists in the 1930s (see Wirth, 1938 and Mumford, 1937), argued that population alone does not define an urban instead the influence that the urban areas exert on the social life of the people is what is more important. Wirth (1938), a Chicago School urban sociologist, exceptionally outlined the precise definitions of urban using three sociological properties. These properties include large population size, high population density, and high levels of demographic heterogeneity see Brenner (2013, p. 90), see also Fox (2013), who simplified the definition of urban provided by Wirth. Further to this, Mumford (1937, p. 93), in an attempt to define what is an urban, added that social division of labour is a significant feature of 'urbanism'. This explanation shows that a is any densely populated area where there is a social division of labour, coupled with a high level of demographic heterogeneity.

Moreover, Lefebvre (2003) noted that the term urban is characterised by

> *" Piles of objects and products in the warehouses, mounds of fruit in the marketplace, crowds, pedestrians, goods of various kinds, juxtaposed, superimposed, accumulated – this is what makes the urban, urban" (Lefebvre, 2003, p. 116).*

This definition as provided by Lefebvre is somewhat ambiguous because not all these factors listed herein are found in an urban centre. In short, this definition makes an urban a kind of an economic centre, because it assumes that cities are made up of moulds of fruit in the marketplace and products in the warehouses. In fact, this definition neglects that some urban centres are administrative centres, social, religious and educational arena (see Myers, 2011). Amin and Thrift (2002) gave another elaborate description of the term urban, according to them;

> *"the city is everywhere and in everything. If the urbanised world now is a chain of metropolitan areas connected by places/corridors of communication (airports and airways, stations and railways, parking lots and motorways, teleports and information highways), then what is not the urban? Is it the town, the village, the countryside? Maybe, but only to a limited degree. The footprints of the city are all over these places, in the form of city commuters, tourists, teleworking, the media, and the urbanisation of lifestyles. The traditional divide between the city and the countryside has been perforated" (Amin & Thrift, 2002, P. 1).*

These elaborations of Amin and Thrift (2002) especially the one that state that city is everywhere further complicates the attempt of getting an exact meaning of the term, urban/city. This study is not an attempt to resolve the complications surrounding the meaning of the term in question, it is an attempt to contribute to unravelling its meaning. Therefore, the term urban/city in this study will be seen as any densely populated and sustainable area that possesses the economic, political, environmental, cultural and social attributes capable of attracting the influx of forced and unforced migrants into it. This leads to the discussion of the concept of sustainable city.

THE SUSTAINABLE CITY

The revision of the 2017 world's population shows that as at the mid-2017, the world population rose to nearly 7.6 billion, in the last twelve years, an approximate of one billion inhabitants was added to its population (United Nations, 2017). This shows that there is a dramatic increase in the overall population of countries over the years. Following the fact that Preston (1979) demonstrated that there is a strong correlation between total population growth and urban population growth, it is easy to conclude that this staggering growth of the population of the world, necessitates an overwhelming increase in the total number of people residing in the cities of the world. This emphasises the reason why it is important to take sustainable measures by building cities that will meet the needs of the present generation without compromising that of the future generation – sustainable cites. According to Williams (2010);

> *"There are now global and local commitments to make urban areas into 'sustainable cities' through various processes of 'sustainable urban development'. Numerous actors are involved in the academic and practical aspects of the endeavour. We see, for example, social scientists, built and natural environment specialists, engineers and artists all undertaking research, and developing strategies and programmes, to tackle elements of sustainable urbanism" (Williams, 2010, p.129).*

This simply means that sustainable cities and the need to build it have gained considerable recognition, also there are efforts geared together by so many actors in a bid to achieve it. Based on this, it can be said that the importance of city sustainability cannot be overemphasised. Then, what is a sustainable city?

According to Bulkeley & Betsill (2005, p. 42), there is less certainty about what a sustainable city means in practice despite the fact that it has been inculcated into policies as desirable goals, and has also commands near universal recognition. Bulkeley & Betsill continued to emphasise that some of the analyses of urban sustainability use indicators, flows, footprints and others to document the extent to which cities are becoming more sustainable, this they see as important but narrow analysis. To Whitehead (2003, p.1187), such analysis merely reduces sustainable urban development to a "technical matter of institutional restructuring, traffic management, architectural design and the development of green technologies". This in effect means that sustainable city is a complex phenomenon and as such it is important to avoid unnecessary over-generalization and or what can be seen as narrowness.

Thus, Williams (2010) concluded that although the concept of sustainable city is an appealing one, it is complex and intangible. Williams advanced that the lack of the precise meaning of the term sustainable city, necessitated most disciplines working in the field of sustainable cities to construct their own notion of what the concept means in their own light. According to him, for instance, engineers see sustainable city as the efficient use of resources with systems mapped with losses and uncertainties identified. He also pointed out that sustainable city in the social sciences, is defined in terms of the goal of 'social sustainability', such goal is realised only when 'a particular conceptualisation of social equity or justice is evident in a spatial setting' (Williams, 2010). It can be argued that these definitions of sustainable city as put forward in these fields are rather more complex and vague with special reference to the latter. In fact, in an attempt to define a complex term, it is advisable to be cautions of the choice of word used in such definitions to nip unnecessary complexities in the bud. Most times, it is not out of place to endeavour to simplify such definitions to a layman's standard for ease understanding.

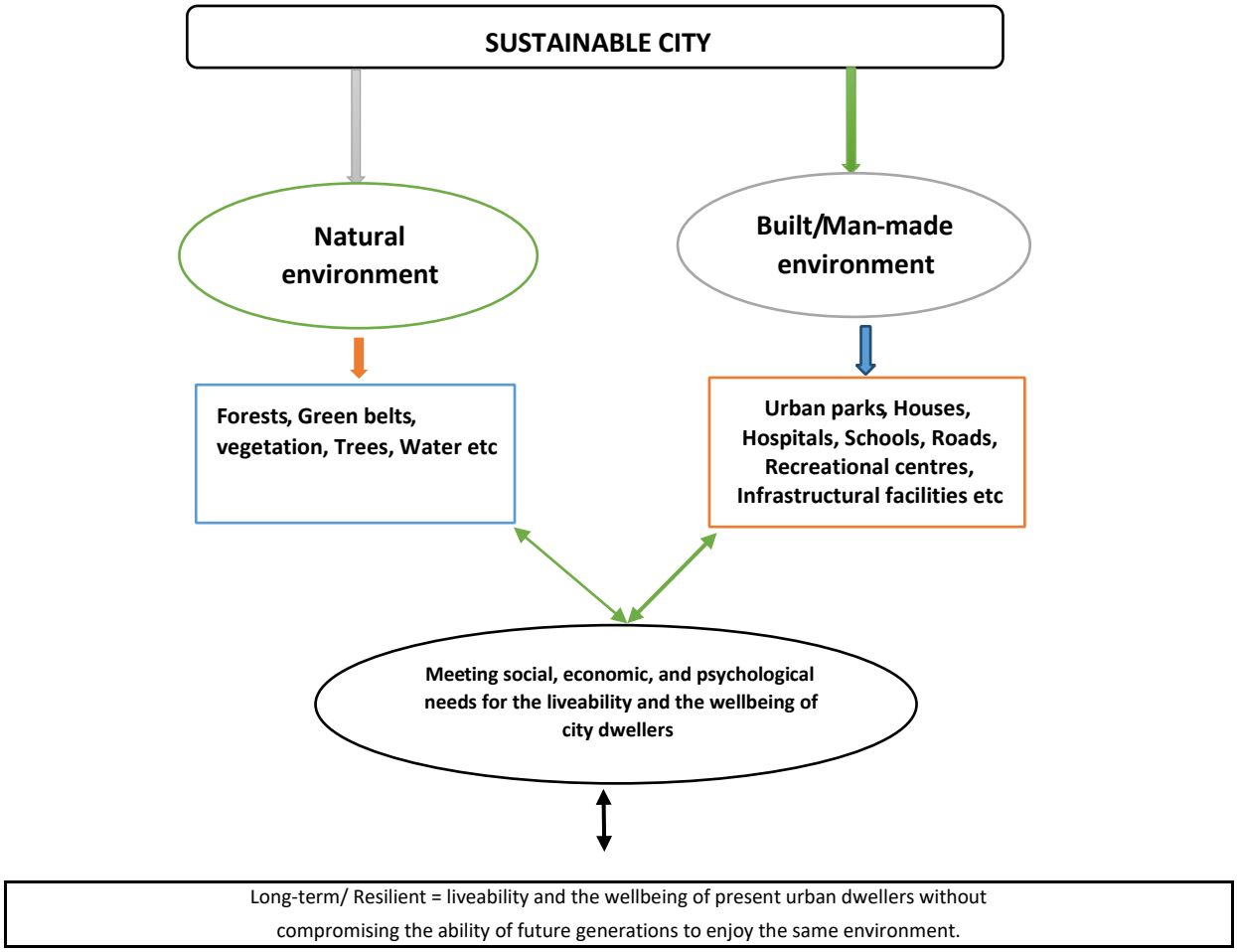
This is why the definition provided by Chiesura (2004) is a more precise and understandable one. According to him, "sustainable city is characterised with regeneration strategies that focuses on both man-made built environments and the natural components and green spaces of urban structure". Chiesura (2004), further argues that the man-made built environments have continued to receive considerable attention in the studies of city sustainability, much more than the natural and green spaces environments, stating that urban parks and green spaces are important for the quality of life in the cities. Chiesura added that the importance of urban parks and green spaces cannot be over emphasised but the other city elements such as social infrastructures; transportation also support the quality of life in the cities. The definition of sustainable city as put forward by Chiesura simply shows that sustainable city is made up of the natural environment and man-made environment and these two must be given adequate and uniform attention if a sustainable city must be achieved.

Chiesura (2004), further provide reasons why he made the claims above. According to him, as the population continues to grow, there is growing empirical evidence which shows that the presence of urban parks and forests, green belts and trees and water which are natural assets in cities facilitates the quality of life in many ways. He further shows that apart from the crucial role of environmental services such as air and water purification, wind and noise filtering, natural areas provide social and psychological services, which are of crucial significance for the liveability of modern cities and the wellbeing of urban dwellers. This is understandable because it clearly shows that one of the essences of achieving sustainable cities is to improve the well-being of the masses in these cities, and such can only be achieved when both the built and man-made environments are in good shape, with each receiving the same measure of long-term maintenances.

However, as rightly pointed out by Chiesura (2004), the said wellbeing of the urban dwellers is dependent on so many factors that are available in the cities, and some of these factors are embedded in the system through the policies that govern the provision these services. In fact, it is the policies that make the provision for the built and man-made environments and ensures its long-term maintenances. So without these policies, their effective and efficient execution, the achievement of sustainable cities may be hampered and the wellbeing of the masses may as well be grossly affected. With the explanation provided by Chiesura, one cannot escape the conclusion that the definition of the term 'sustainable city' as provided by Chiesura is both comprehensible and straight to point.

Therefore, in this study sustainable city can be seen as a city that has conducive natural and man-made environments that provides long-term/resilient social, economic, and psychological services that are of paramount significance for the liveability and the wellbeing of present urban dwellers without compromising the ability of future generations to enjoy the same environment. For clarity, we will represent the concepts in this definition in a framework to show at a glance our definition of the term sustainable city.

FRAMEWORK SHOWING THE MEANING OF A SUSTAINABLE CITY



The above is our suggested meaning of the concept of sustainable city. Kadiri (2006), further corroborated that the issues of sustainability are principally directed towards the environment in the developing countries. There is need to emphasise following the idea of Kadiri that these sustainable issues are characterised by the developments which involves the long-term survival of the planet and its processes of diverse evolution, including the wide range of species that currently live on it, not least humankind. The above is the kind of city that will address the concerns of scholars regarding the lack of sustainability of the cities in the Niger Delta region of Nigeria. If the government and policy makers could work to achieve the kind of city as represented in the above framework, it will contribute to the development and well-being of the people of the said region in a long run.

Despite the importance of sustainable cities as shown above and the fact that it has been promoted as a desirable goal, it is bedevilled with some challenges. According to Bulkeley & Betsill (2005), such question regarding the extent to which the cities and the local governments can address the various challenges of sustainability has not been answered. Indeed, there are challenges that bedevils every field of study, although the extent of such challenges to mitigate against the achievement of the desired goals of diverse fields of study differs. As a result, what is required most times is to overlook some of these challenges and concentrate on the maximization of the potentials of the said field of study. In this study, this is exactly our approach to the challenges of sustainable cities, because the exploration of the challenges of sustainable city is not within the purview of this study.

Nevertheless, the point raise by Haughton (1999), that sustainable city cannot wholly be achieved on internal terms only; that the city can make an efficient and effective contribution to the global aims of sustainable development, where a process as an endproduct is seen as much as sustainable development; is an important one. According to him, creating a sustainable city in isolation is a near impossible action considering the increasingly global exchanges of environmental resources, and global economic trading and waste streams. Haughton advanced that a city can be considered as unsustainable if it centres solely at the local level relying merely on the appropriated environmental assets of its locality. This can be said to mean that there should be some measures of intra and interconnection of local cities with the rest of the cities of the world for a city to be sustainable. This a good idea, and something that need to be imbibed by countries who are working hard to achieve sustainable cities.

RESEARCH METHODOLOGY

The methodology approach for this research is a critical review of the literature, which analysed concept, framework and opportunities mainly on the basis of academic literature on sustainability in the built environment. Unlike the use of the qualitative and quantitative methodology in an empirical research aimed at generating fresh data, this study is a literature/library base research aimed at using secondary sources to generate possible opportunities in the Niger Delta Region. It aims at reviewing various relevant existing literature and publications. These secondary sources include the review of books, dissertations, journal articles and reports from United Nations, World Bank, UN- Habitats which were gotten from the internet sources. These data were summarized, analysed, synthesized, and evaluated to get the desired results. The data in no small measure helped to understand what a sustainable city is all about the benefits that can be harnessed from it.

FINDINGS AND DISCUSSION

This study review literature on migration, urbanisation and sustainable city and found out that the migration-induced rapid urbanisation in some of the developing countries of the world today with special reference to Nigeria and its Niger Delta region requires an urgent shift to the thinking of the acquisition of sustainable city. It shows that the continuous migration of people from the rural to urban areas is becoming prominent and invariably increasing population

growth in the urban centres with challenges to sustainable development also increasing. A peculiar challenge identified is the forced migration as a result of seeking for the necessities and improved or better life. Some are displaced due to war and conflict in their regions, causing them to migrate unwillingly to the cities. A particular framework is the push and pull migration framework describing the reasons why people migrate from one place to another with the difference in income and living standard a critical factor for this.

In fact, the review has shown that the rate at which the urban population in the developing grows has necessitated a growing concern on how sustainable the cities can be now and in the nearest future. In the discussion on the concept of sustainability, it is said that for a city to be sustainable it must possess the quality to meet the needs of the present urban dwellers without compromising the ability of the future generation to meet their needs from the socio-economic, environmental issues supporting the process of sustainable development. Importantly, Chiesura found out that there are two main components of a sustainable city which include natural environments and man-made or built environment. Chiesura also decried that little or no attention has been paid on the natural environments, the environments he affirms that possesses some of the important factors that benefits humanity. According to him, the natural environment complements the built environments in producing a liveable city geared towards promoting the well-being of the masses. He also emphasises that for more robust cities to be able to sustain itself overtime reflecting in the quality of life of the populace, elements in the cities such as the parks, utilities, amenities, facilities should complement and not conflict each other.

It was also discovered from the literature that policies have a crucial role to play in ensuring the achievement of the sustainable city in a region like the one under study. Importantly, the actions of the population in these cities is also a determining factor to a sustainable city, in terms of the culture, way of life and habit. These actions are mostly seen through the deforestation, land degradation and decay in the urban cities. Another argument also shows that the achievement of a sustainable city should not be in isolation rather it has to link with the rest of the cities in the world, otherwise it is a near possible to produce a sustainable city in isolation. In fact, we acknowledge the importance of this observation made by Haughton, because sustainable city has a lot to do with sustainable development.

How consistent sustainable development is over time allows for a city to continue to grow in population through migration and urbanization which affect socio-economic and environmental issues and gives rise to more opportunities to remain sustainable through more investment, increase in labour force, improve quality of life through improved living conditions, improved wages or income. However, if these opportunities are not well harnessed and controlled it can become unsustainable and can affect development in the cities in a long run. These opportunities can translate to health care facilities, basic and social infrastructures, amenities and utilities which would increase commercial, industrial and tourism activities.

Therefore, it is recommended that efforts should be geared towards the achievement of sustainable cities in the Niger Delta region of Nigeria by focussing on both the man-made environments and natural environments. Measures should be taken to ensure that these environments are long-term and resilient, receiving adequate maintenances. While the built environment comprises of the man-made structures, natural components which plays significant roles in a sustainable cities and this can be achieved by surmounting socioeconomic and environmental issues. The natural environments are everywhere ranging from the forests,

the trees, the green vegetation, the air, the water etc., all of which needs adequate maintenances.

CONCLUSION

Importantly, the need to continue to strive for sustainable cities is the responsibility of everyone including the government and policy makers who interact with the environment through policies and actions by fostering greater relationships between the migration and urbanisation which will translate to sustainable development over time. It is therefore recommended that further research should be conducted on the challenges of sustainable cities and possible remedies, as well as the opportunities of sustainable cities. This will continue to improve the sustainable development agenda in the cities around Nigeria and the world with the support and collaborations of the stakeholders in the built environment as mentioned above.

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SUSTAINABLE FACILITIES MANAGEMENT IN NIGERIA AND UNITED KINGDOM

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Keywords: Sustainability, Facilities management, Built Environment.

Abstract

The built environment is essential in attaining the sustainability agenda, as a result of the impact of facilities management on day to day activities in an environment where people work, live and play. Sustainable environment is one of the most challenging issues facing the facilities management industry in the developed and developing countries. This study sets out to compare and contrast the common best practices of sustainable facilities management amongst practitioners in Nigeria and United Kingdom. To achieve this aim, there is a need to identify the best practices from both regions in order to learn and implement for sustainable growth in the industry. The study adopts the mixed methods with an extensive literature review which informed the use of structured and designed questionnaire survey to focus groups (facilities managers in different organizations) in Nigeria and United Kingdom. The findings show the differences between both regions in energy management and reduction, waste management and recycling, preserving the natural environment. The level of awareness of sustainable facilities management in United Kingdom is high compared to Nigeria. There is a high level of support from government and regulatory agencies for the industry in the United Kingdom. In Nigeria, the support from the government, regulatory agencies, top management levels are inadequate. The study concludes that facilities management practitioners in Nigeria must practically engage with top management, government and regulatory agencies in order to influence policies and decision making in promoting sustainable facilities management and recommend more collaborations with professionals (Builders, Engineers and planners) to efficiently and effectively improve the environment and industry.

INTRODUCTION

The facilities management professionals that are successful in the world, pride themselves high based on their knack to always be at the top of the game in the aspect of making the built environment conducive for people from all works of life to work, play and live (Jaye, 2012). The importance of the profession to the built environment is so enormous, so also is the urge to provide the best form of services and options for improvement is increasing by looking for proactive measures through developments and trends that will have impact on the people and environment directly or indirectly (Global Reporting Initiative, 2011). This environment encompasses places and spaces which can be created or modified in various forms by people to achieve their aims and objectives. Facilities management profession recognised the fact that the built environment's potentially as a significant role in the sustainable goals which was well documented by (Wood, 2006; Shah, 2007). It was further suggested that the built environment

has significant impacts on the sustainability agenda, where it accounted for nearly 40% of waste and greenhouse gases generated and 40% of limited natural resources consumed (Chartered Institute of Building, 2004). Elmualim et al., (2010) and Shah (2007) opined that the role of facilities management has a significant influence over how facilities and buildings are used and therefore tasked various facilities managers to promote and implement the sustainability policies within their organisation. Sustainability policies and drivers directly influence facilities managers' activities; however, current research on sustainability policies and drivers influencing the activities of facilities managers is limited. Hence identifying the key issues and drivers will reveal how facilities managers are engaging with the sustainability agenda in the United Kingdom and Nigeria. It is pertinent to note that more recently, the (International Facilities Management Association Report, 2007) examined that sustainability was the key issue that practicing facilities manager were facing and were challenged to carry out sustainable development and practice.

However, the rapid pace of development over time in developing and developed countries makes depletion of environmental resources a growing global concern. As seen around the world, an increasing number of building owners and governments are asking for their buildings to be more energy efficient and sustainable (Lawanson 2006). In many areas or aspect, government mandates through policies for sustainability already exist or are anticipated, but many organisations around the world are still waiting to be sanctioned before pursuing sustainability, while some have accepted the fact that it worth pursuing. The need to identify, assess, manage and monitor the organization's performance is becoming a critical issue to attaining sustainability (Ferguson and Langford 2006). Adopting a strategic approach to facilities management is becoming important and the norm for an organization. An effective role in managing the facilities shall be a critical part in financial performance and sustainability (Roper and Beard 2006). So therefore, it is based on these issues identified by various researchers, that this research is conceived to identify what is perceived to be the common best practice or practices to sustainability, when managing the asset or facilities that support the core business of an organization from the perspective of a developing (Nigeria) and developed (United Kingdom) country.

In view of the identified issues, the aim of the research is to compare and contrast the common best practices to sustainable facilities management amongst facilities management practitioners between Europe, United Kingdom and Nigeria. In order to achieve the aim of the research the following objectives are set to identify the different approaches or attributes to sustainable facilities management in Nigeria and United Kingdom, identify challenges or barriers to sustainable facilities management in Nigeria and United Kingdom and to identify and explore the common best practices to sustainable facilities management in Europe, United Kingdom and Nigeria. To achieve these objectives, there are pertinent questions that the research tends to find answers to, some of these questions are; what are the common best practices to sustainable facilities management? What are the challenges associated to sustainable facilities management and what are the approaches to sustainable facilities management? Facilities management is relatively a new field internationally including Nigeria, especially Lagos, south west which was the formal capital of Nigeria (Adejumo et al., 2009). Lagos is the commercial hub of Nigeria, where the profession is thriving from year to year because of the reputation of the city in terms of presence of investment and diversity of all residents in the region, so this study will take an exploratory approach trying to compare and

contrast the common or best practices to sustainable facilities management in the United Kingdom, Europe and Nigeria. In view of this, the study will rely extensively literature done by researchers, considering the level of awareness, approach, challenges, policies to sustainable facilities management and also carryout survey to further confirm its findings from the literature review and this survey will focus on the facilities managers in United Kingdom and Nigeria to enable the study critically compare and contrast what the common best practices are, within these regions to achieve it aim and objectives. The literature will focus on the built environment, component of sustainability and facilities management.

THE BUILT ENVIRONMENT

According to Smith et al., (1998) the built environment comprises of our places of work, leisure and homes, which is what forms the image of our villages, cities and towns. The structures which is within us provide retreat and cover and can also promote within us belief of health which makes us have a mix of associations that comes from place and of belonging.
However, for the built environment to be fully formed and vibrant, one cannot take away the role or importance of the construction industry. Russell et al., (2007) states that the construction industry is so important that its account for more than 12 per cent of the national GDP and provides civil infrastructure that is critical such as roads, rail, water, bridges and treatment for waste water, plants which produce energy for transmission and facilities which includes houses in which we live in, office buildings in which we work. Pearce et al., (2012) further describes the construction industry as the biggest in the world, due to the provision of essential facilities for human richness from the variety of homes where people live, to the highways people drive on, the energy we consume on a daily basis through power plants, and the social amenities or infrastructure that the society thrive on. Due to these construction activities of creating a built environment, which includes operation, maintenance, demolition, refurbishing and construction of built facilities, associated problems and issues are created which affects the environment such as global warming, water pollution, air pollution, land pollution, climate change, ozone depletion, deforestation, desertification, soil erosion, loss of diversity, acidification, depletion of fisheries and consumption of valuable resources such as minerals, all this affect the built facilities significantly in terms of health, comfort and productivity (Pearce et al.,2012).

SUSTAINABILITY

The term sustainability has different interpretations or meaning to different people depending on the context or area it's viewed from. But in the built environment, what is considered to be sustainable is seen from the building development perspective which involves the clients, designers, financial sources, builders, special consultants, suppliers, government bodies, regulatory bodies, facilities managers and all these stakeholders will find a common place to interpret what sustainability is all about. However, there is challenge of having some conflict on the understanding of a shared idea (Ellingham and Fawcett 2013). According to (IUCN 1980) the term 'sustainable development' was first mentioned at the World Conservation Strategy meeting in 1980, the aim of the meeting is to conserve living resources which will help advance the achievement of sustainable development. After the strategy meeting, the sustainable

development is now commonly called or known as an idea in Our Common Future, which is as a result of Brundtland Commission on Environment and Development findings and popularly known as Brundtland Report (WCED1987). This report defined sustainable development as the 'development that meets the needs of present generations without compromising the ability of the future generations to meets their needs and aspirations' (WCED 1987). The report also laid down some actions necessary to achieve sustainable development such as;

- Eliminating poverty and deprivation.
- Conserve and enhance natural resources.
- Incorporate economic growth and ecological decision making.
- Encapsulate the concepts of economic growth, social and cultural variation into development.

However, Ellingham and Fawcett (2013) argued that Brundtland report is not definitive, that groups that focus highly on the natural environment claim that the definition is too humancentric in nature, while industry often sees them as too focused on the environment and in the developing world they view the report as representing a set of values being imposed by the rich and that will also limit opportunities for the less privileged.

FACILITIES MANAGEMENT

This section will carry out an overview on facilities management at various levels considering the definitions from different bodies, countries, organisations, their approaches to facilities management in general. According to IFMA (2013) describes "facilities management as a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology". From the definition, IFMA (2013) also offers an over view of the multidisciplinary nature of facilities management which is attributed as the competency areas, these are summarised below:

I Operations and maintenance
II Real estate
III Human and environmental factors
IV Planning and project management
V Leadership and management
VI Finance
VII Quality assessment and innovation
VIII Communication
IX Technology

According to Atkin and Brooks (2009) it may be challenging for organisations to be mindful of the magnitude to which facilities management can be improved upon in terms of searching for the best value or value for money. Which shows why the result does not need to be examined, but must be based on the assumption made which eventually leads to decision making. Atkin and Brooks (2009) also suggested that there are common approaches and themes to facilities management, irrespective of the location, design, nature of buildings, and nature of business or organisations. Meanwhile these may not get certain result in common solutions to problems. That is why in some cases the services are done in house or contracted out which may be for a

good reason for each case. Any action taken is solely dependent on the organisation decisions which are backed by reasons that usually demonstrate better value for money as it where the approaches adopted and working effectively and efficiently for the organisation.

THE RELATIONSHIP BETWEEN SUSTAINABILITY AND FACILITIES MANAGEMENT

The role of sustainability on facilities management cannot be over emphasis as organisations continue to tow this line through the development and implementation of sustainable policies, these policies are then put down through strategic actions and evidence of progress can also be demonstrated. Due to this development a growing number of companies throughout the building supply chain, including property owners, service delivery companies and investors are processing, implementing and developing policies (Shah 2007). However, the co-ordination of the activities and policies by the stakeholders in this chain identified has been a challenge, because this is needed to show that the objectives of the policies are being met and observed.

Furthermore, the facilities management industry has a role to play through the top down approach by influencing management hierarchy and colleagues within their capacity in an organisation to understand the role of sustainable development in terms of benefits and impacts it has on the environment, physical and social context in relation to service delivery like fair pay, controls of procurement, waste controls and reductions and energy reduction. More so, from a strategic point of view, facilities management play a significant role within an organisation, business, and utilising property performance metrics to support the process of decision making and the concept of sustainable facilities management has grown in line with the concept of sustainable development which has also appreciated in the growth in the scale of predicted climate change (Shah 2007). This was evident recently in intense conditions like the Hurricane Katrina, flooding in South East Asian and with all these conditions the urge to reduce the threat of global climate change has increased as well, but for these conditions to be reduced, there is a need to consider the balance of the three concept of sustainable development – social, environmental and economic. Facilities management professionals should be at the forefront for change and build up practical goals within the sustainability framework (Elmualim et al., 2008). Due to the role of the evolving profession, facilities managers are now in a strong position to effect changes in terms of organisational behaviour and also influence the individuals working in government departments, public services, business within their capacity and the facilities they manage. In view of this, government at the national and international level are using policies like regulations to manage energy demand and lessen carbon emissions. These regulations would be at the facilities managers' disposal at every level and at any organisations they find themselves (Shah, 2007; Elmualim et al., 2008).

BARRIERS/CHALLENGES TO SUSTAINABLE FACILITIES MANAGEMENT

The traditional way of working for facilities manager, where they are known for attending to end users' complaints and carrying repair works on site is no longer seen as suitable these days (Kincaid, 1994; Barrett and Baldry, 2003). This is as a result of the rapid development of technology and the effect on the users' and their needs. As technology keeps changing so are the needs of the user's keeps changing and becoming complex to deal with (Pitt, et al., 2001).

So due to this, the facilities management profession has to adapt to these changes and develop ways in dealing with these challenges by being innovative in the ideas and being at the forefront of the organizations policies.

According to a study carried out by Elmualim et al., (2005) discovered that the challenges for Facilities management industry is to improve the effectiveness and efficiency of communication between facilities managers and other professionals in order to eradicate the susceptibility of the building design and operation. Elmualim, et al., (2009) further opined that the inefficient and ineffective communication amongst themselves and other professionals leads to the gaps in knowledge and as a result hampers the development and continuity of knowledge. However, due to the exposure in the facilities management industry which has a combination of multi-disciplines, it is expected that there should be better quality of services and facilities but this is not the case in some cases because of the exposure to the impact of a lot of professional interest (Shah 2007).

Hodges, (2005) argued that in the construction and property industry, facilities management is reasonably new, that facilities manager's involvement at the early stage of the development process is not seen as important these days but see their role at the operational stage more needed and further opined that the involvement of the profession should be done to push these ideas into the industry's policy and culture. However, the commitment and the perception of facilities managers practicing the profession is another area of great concern in the industry towards sustainability agenda and this aspect is very vital and can be a barrier to the growth of sustainable development. Mckinsey Quarterly Global Survey in 2008 examined the attitudes of older executives and their role in the sustainable agenda, this survey discovered different and puzzling attitudes among the older executives with different perceptions on the issues, with about 60% observed that climate change is very key within the overall strategy of their companies, while virtually 70% see it as a reputational issue and key branding to their companies. Meanwhile, about 30% contemplated that the issue of climate change is the very key world trend that their company usually face which is quite different from a report by Stern which suggested that in the next century climate change is the most important driver for policy (Pitt et al.,2001). More so, it was also identified that there is a correlation between bigger organisations and a dearth of involvement by older managers. The disparities are that with better understanding or involvement in smaller organisations, financial limitations may affect the level of progress (Mckinsey Quarterly Global Survey, 2008).

Time insufficiencies to concentrate on the issues of sustainable facilities management is also a source of concern due to the diversification of the profession as a whole, this makes it difficult to address issues that pertains to sustainability and also serve as a barrier to implement on the long run (Elmualim et al., 2008). Lack of knowledge and collaboration has been stressed from the sustainable perspective within the facilities management industry to efficiently and effectively manage facilities as it where due to the diverse and inconsistent nature of the facilities management profession. This is seen as a result of insufficient training, inadequate experience across board when readily needed (Shah 2007). Meanwhile Brand et al., (1999) argued the need for a more collaborative approach is essential in terms of introducing new agenda of sustainable development and referred onto the experience from Europe which has brought about a fresh emphasis on shared responsibility under the Fifth Amendment Action Programme. This action suggested a unique approach to industrial ecology and ecological

modernization in encouraging industry towards sustainability. This suggestion of collaborative approach was further supported by Carpenter and Meehan (2002), who opined that Facilities manager, should be part of the mainstream within organisations. According to Elmualim et al., (2010) in a survey, it was perceived that barriers and commitment to the introduction of sustainable facilities management across the industry as a common practice.

RESEARCH METHODOLOGY

The exploratory techniques adopted to achieve the aim and objectives of this research was very critical to the study, most especially the review and analysis of the website content of facilities management servicing companies or organizations, to understand the different strategies, concept and approaches to sustainable facilities management. This was done together with literature reviews, books, journals and report by researchers such as Adejumo et al., (2009), Adewunmi et al., (2012), Atkin and Brooks (2009), Elmualim et al., (2010) and reports from the International Facilities Management Association (IFMA), British Institute of Facilities Management (BIFM) and some other relevant researchers and regulatory bodies which informed the process of the questionnaire design and approach. The questions adopted for the questionnaires were based on the research done on the servicing companies to identify gaps and areas of interest to target in terms of the focus groups and population. This was also helpful for data collection through the use of survey tool to distribute and administer questionnaires to both area of study. The data collected were processed and analysed accordingly using tables and charts to present and interpret them in order to draw out conclusions and states recommendations where necessary.

SUMMARY OF FINDINGS & DISCUSSIONS

Based on the analysis done, it is evident that the main motivation for this research work is to compare and contrast the common best practice to sustainable facilities management amongst facilities management practitioners between Nigeria and United Kingdom and possibly transfer lessons learnt from both regions between the regions. Major highlights of the results obtained from the analysis are summarised as follows:

Table. 1 Showing summary of findings from the research.

NIGERIA	UNITED KINGDOM
I. Nigeria's efforts towards the aspect of the environment are marked by policy formulation and one of the local environmental laws enacted is the Land Use Decree of 1978. Furthermore, there is also a national policy on Environment (1989), which is concerned with conserving and using the environment for the benefit of present and future generations but there is no proper system in place to keep it running as expected.	I. Environmental aspect was pointed out and identified as the concept needed in the university and promoted through the incorporation of three strategies such as the University Environmental Management System (EMS); using teaching and research to promote sustainable facilities management; and also adopting the public participation and social responsibility.
II. The energy performance and generation is grossly insufficient; and the need to encourage energy efficiency culture is high. The energy generated is mostly from burning of fossil fuel (oil and gas) and for electricity generated or consumed the more emission of greenhouse gases.	II. The Energy efficiency and performance is regarded as one of the major approaches to sustainable facilities management with the availability of regular power supply and the need for sustainable energy performance and reduction being at the forefront of every organisation through managing energy demand and lessen carbon emission.
III. Even though Nigeria is part of the International Conventions on Biodiversity Climate Change, Desertification and other bodies governing climate change. The approach towards reducing the effect of climate change is nothing to write home about compared to developing and developed countries due to being part of the signatory to the Kyoto to the Framework Convection of Climate Change.	III. The climate change is one of the areas highlighted by and was further supported by the Organization for Economic Cooperation and Development (OECD) that about 32% of the world resources are consumed by buildings. Level of communication between facilities managers and other

IV.	Lack of communication and understanding between facilities managers and other professionals is also one of the challenges towards sustainable facilities management.		IV. professionals which hampers the development and continuity of knowledge.
V.	The level of support from different bodies as well as the government is not as high as it counterpart in the world, but the corporate organisations such as the oil companies are encouraging the practice towards sustainable facilities management due to the level of expertise they have within their workforce.		V. The level of support from different bodies is high to attain the best practice towards sustainable facilities management is evident and pioneered at every level from the hospital, universities, nongovernment organisations.
VI.	Average level of awareness to sustainable facilities management.		VI. Level of awareness to sustainable facilities management is very good.
VII.	Slightly above average of the respondents' claims that there is level of approach to sustainable facilities management.		VII. Approach to sustainable facilities management is available according to all the respondents form United Kingdom.
VIII.	Ways of measuring performance against the policy or plan are; through the number of man power and hour during the year in review, through ISO 9001:2008 audits as against the procedures and processes laid down by the organization and through meeting 95% customer satisfaction from the feedback done during the year in review.		VIII. Ways of measuring performance against the policy or plan are; through the reduction of carbon di oxide and setting recycling target as well, through green impacts and ISO 14001 audits and through meeting targets of core areas such as energy, by the reduction of consumption of energy use over the period of the year in review.

IX. In comparison with the respondents from United Kingdom and Nigeria, energy saving and consumption, waste management, disposal and recycling and management and reduction of carbon emission were said to be the common best practices to sustainable facilities management. However, in contrast to the respondents from Nigeria, reduction of air, land and water pollution, involvement and commitments of high or top level management and also effective and efficient communication were mentioned from the respondents from United Kingdom.

X. The similarities to sustainable facilities management from United Kingdom and Nigeria as identified from both respondents were the execution of work through health, safety and environment, effort in managing waste and conserving energy, effort in conserving the environment through pollution reduction and environment management practices. While the differences from the United Kingdom compared to Nigeria were inadequate support from government and regulatory bodies, inadequate awareness in the benefits of sustainable facilities management, level of compliance is high and infrastructures are more available, it is part of the culture and finally the level of exposure to training is adequate and relevant.

CONCLUSION

Whilst the findings in this research suggest that the awareness to sustainable facilities management is becoming prominent and understood by facilities managers and servicing companies, especially in a developing country like Nigeria when compared to the United Kingdom, knowing that the facilities management profession is relatively young in Nigeria as evident from the study. This assertion would need to be taken into account before a general conclusion can be done. However, having said that, from the results of the questionnaire survey, it shows that there is possibility to have a level comparison between Nigeria and United Kingdom towards sustainable facilities management due to the concept of sustainability itself. This concept is mostly driven by organisations/companies which informed where the comparison is gotten from. As organizations become more familiar with the sustainable facilities management practices their plans, policy and decision making process evolves.

As this evolves, it is passed down to facilities managers who put these policies into practice, driving towards economic, social and environmental concept of sustainability. The result from the questionnaire survey also identified approaches, challenges to sustainable facilities management as put in the objectives of the study and this also informed the possibility of comparing and contrasting the challenges and approaches as its affect their organizations, which allows the study to identify where they are affected most. So therefore, because sustainable facilities management means different things to different people, organizations and bodies, as sustainability concept is quite broad. The organisations plan, policy or strategy is seen to be very significant to the approach and challenges towards sustainable facilities management and these makes it really difficult to ascertain the best practice but comparing and contrasting the common best practice towards sustainable facilities management between organisations and regions had been useful as evident from the results of the questionnaire survey done for this research.

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NOMINATION DREAMS: ELUSIVE DIFFERENTIATION AND NEW ENTRANT CHALLENGES. EXAMINING STRATEGIC OPTIONS FOR UK CONSTRUCTION.

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Key Words: Sustainable strategies; Strategic Analysis; Construction differentiation.

Abstract

Strategic options for construction firms operating in Irish and U.K. markets might be limited to the cost leadership strategy outlined by Porter (1985), with attempts at differentiation becoming not much more than Public Relations exercises with little impact on client buying behaviour. The constraints that exist to maintain 'price leadership' erects a significant barrier to sustainable construction because clients and contractors have an emphasis on minimising capital expenditure at the expense of other considerations; notably sustainable building for medium to long term returns. This paper discusses factors that conspire to maintain a focus on capital cost reduction and the consequential negative impact on sustainable building. The paper compares the construction market with other Asset Management examples in three selected illustrations from the authors' own primary research or literature, to explore how entrenched is the industry is in constraining suppliers from developing differentiation strategies that would allow for a focus on sustainability and possibly make them a first choice for clients, in the way retail markets see customers prefer brands. Identifying core conditions and barriers that influence 'price leadership' strategies for construction, and long term partnerships in other industries, this paper proposes a study to test its hypothesis "Contemporary attempts by construction firms to differentiate are merely further methods to improve price leadership competitiveness" by proposing a study that will 'test' existing differentiation strategies evident in the market. Some possible ways construction firms might move towards successful market differentiation strategies, and lift existing commercial barriers to more sustainable construction are suggested.

INTRODUCTION

Recent definitions of 'sustainability' are not limited to considerations for 'carbon reduction' or even environmental impact; they also include a consideration for economic and social impacts (Zhang et al., 2014). For instance, Dillard and King (2008) suggest that sustainability is a compelling need to meet a 'triple bottom line of the financial, social, and ecological' interrelated dimensions to ensure the maintenance of the global system. The modern definitions of sustainability were consistent with the concepts of sustainable development in the Brundtland report, 1992 (Brundtland Commission, 1987). The world commission on environment and development indicated that the "direction of investments" should target the achievement of sustainable outcomes. Moreover, Ogunbiyi et al. (2014) and Presley and Meade

(2010) argued that definitions of sustainability may have been skewed to address the contemporary business interests.

With respect to the construction industry, previous research tended to focus on the outcome of sustainable building practices; built assets that consume less energy and materials, in addition to providing a more sustainable ways of living (Glass, 2012). However, the impact of sustainable practices on the business performance of construction contractors remains under-investigated. The challenge for contractors is to ensure that sustainability is present and integrated through the diverse operational functions in construction projects (Glass and Dainty, 2011).

A scant evidence base suggests that the construction sector in the UK lags behind other industries on integrating sustainable practices. Nevertheless, the purpose of this paper is to clarify the current status of sustainable construction in the UK. Moreover, it aims to define a research framework for the future development of sustainable construction.

LITERATURE REVIEW

Sustainable practices in this study refer to practices aiming to achieving sustainable development in the delivery of construction projects. These practices take place in the preconstruction, construction, and post construction stages of a construction project cycle. Sustainable practices in construction includes sustainable design, procurement, site waste management, materials and resources use, and operation cost during the overall project lifecycle (Opoku et al., 2015).

Unfortunately, the building practices of British construction firms are not considered sustainable even when examined from the narrowest of financial perspective (Glass, 2012; Opoku et al., 2015). The modest emphasis placed on sustainable development could have a negative impact on the business performance of construction contractors in both nations. A more-sustainable building practices might require increasing the initial capital investment. However, it was found that embracing sustainable practices positively influence the strategic performance of building contractors through clients' satisfaction and acquiring a competitive advantage (Eilers et al., 2016).

The reason beyond the modest emphasis placed on sustainable practices in the British construction industries remains unbeknown. However, one can posit that the problem resides in the dated procurement approaches dominating the contractual relationship between construction parties. These worn procurement approaches encourage: a persistent and primary focus on capital purchase cost, powerful leverage from the client; established competitive dimensions that involve only capital price competition; and the fragmented nature of the construction industry.

A persistent and primary focus on capital purchase cost;

Construction buildings involve large (often single investor) risk commitments for clients in comparison to other investments that usually enjoy risk sharing among stakeholders. Moreover, the output of the construction process is characterised being highly expensive (Hillbrandt, 2000). Therefore, investors are primarily concerned with the capital risk. One of the traditional methods of risk minimisation is reducing the capital build cost to the minimum.

Powerful leverage from the customer/client;

Construction clients enjoy a powerful leverage due to the fragmented nature of the construction industry. The client's decision is regarded as fundamental in setting up the framework for all construction activities undertaken by contractors (Ofori, 2006). Clients aided by the fragmented nature of the construction industry seek to assure 'value for money', focus on capital costs. To counter this issue, the British government has incorporated the concepts of sustainability in all the procurement processes of goods and services. The modern procurement system falls under the national strategic framework for attaining sustainability, "Securing the Future" (HM Government, 2005). However, the application of sustainability principles in the British construction industry remains lagging its application in other industries (Ofori, 2006).

Established competitive dimensions that involve only capital price competition;

In the construction industry, it is assumed that once the project details have been specified, the quality of the construction output cannot be compromised by seeking lowest price bid (Eriksson and Westerberg, 2010). However, this assumption tends to be flawed since predicting an accurate cost of project details into a near future is a complicated process. Exogenous variables represented in market fluctuations and changing operational conditions means that accurate pricing is unachievable. Therefore, capital price competition is likely to create regular disputes and claims between clients and contractors seeking to address the shortfall in construction costs.

Reflecting Porter's (1985) strategic analysis of the prevalent industries, the construction industry currently resides in the cluster labelled *commodity market*. Porter (1985) posited that competition in commodity markets is often based on providing lowest price of products/services for clients. Arguably, *price leadership* is not conducive to creating sustainable buildings. Sustainable construction usually cost more at capital purchase; however, sustainable buildings offer a greater long-term return by: using less energy and requiring less maintenance over time.

The alternative to 'price leadership' as postulated by Porter (1985) is *differentiation*. Construction firms that seek to differentiate themselves by offering 'sustainable' buildings are not significantly present in the UK market. The structural barriers in the industry are important considerations. While significant technological strides have been made in more sustainable construction, there is what appears to be an inbuilt reluctance to their use and adoption in practice.

This paper posits that the most important challenge to creating construction firm offerings that are differentiated around sustainability is the structure of the industry itself, not the availability of the sustainable technology. Two courses of action can possibly change this situation; one might be the legislation forces to impose an industry change, or that new entrants innovate solutions to challenge the existing competitors. Identifying the flaws in the existing industry structure, and its predictability is how entrepreneurial 'new entrants' spot so-called 'market gaps'.

Three illustrations are used below to examine what barriers to change exist for construction.

Illustration 1: 'Contractor Pumps'

U.K. manufacturing in some sectors produce two categories of product that might be defined as: best product and products for 'contractors'. This seems best illustrated by a simply example of so-called 'contractor pumps'. These products are designed to either: be a cheap to buy as possible, with all medium to long term performance is sacrificed to achieve low production costs, and consequently, in the case of pumps, run hot and require significant maintenance. Or, to be sold at 'less than manufacturing cost' prices, relying on operational failures to create a demand for spares and maintenance and so seed a future income to justify the low purchase price. A domestic example is vacuum cleaners that need 'bags', the market for 'bags' was where the profit margins resided for these manufacturers, the actual vacuum cleaners made no profit to speak of.

The fact that these poor performing products are referred to as 'contractor' pumps might be telling. The desirability of poor performing technology that might be very cheap drives a supply market, that in the U.K. can be observed to create at least two ranges of products, one for contractors and one for the discerning buyer who wants more sustainable performance, that involves a longer asset life using less energy. Chinese manufacturing is able to meet this market demand readily, lowering costs, but not achieving sustainable value. It is worth noting that the market for cheaper Chinese products would not exist without construction industry buyers.

Illustration 2: 'Private Finance Initiatives' (PFI and PF2)

Much use of PFIs have been made in the U.K. to renew public sector assets, most notably schools and hospitals, though also many other assets examples of which are: waste recycling centres and police stations. The premise of these approaches was that the constructor 'Built, Owned, and Operated' (BOO) the building asset and so this procure method dealt with the problem of constructors not being motivated to design for the future operation of a building. In a PFI contract the builder will also be an investor and receive an ongoing income for the maintenance of the operation of the building and also suffer the threat of 'deductions' if the asset is not available for its intended function. The intended consequence of this is that the constructor is motivated to build a building that is sustainable in a number of ways (largely financial), uses low energy, easy to maintain, and is flexible in operation, and that contractor enjoys a more predictable and easy to achieve income as a result. The actual practice has not seen this readily achieved, as facilities contracts have been outsourced by the BOO contractor to the lowest price bidder. The facilities management sector may have a worse reputation than construction, also arising out of cost competition. PF2 differs as an

'improvement' from PFI by removing the facilities contract aspects, arguably defeating part of the design link advantage. The design of PFI and PF2 contracts perhaps failed to account for the vulnerability to the contractor as investor who was also taking a capital risk. There are examples of contractors off loading this risk, post construction, selling their share in the money markets, and in doing so making quick capital gains and reducing their exposure to future under performance of an asset they built. There have also been some high profile examples of building standards on schools not being met, and buildings that it was thought would be immune from poor workmanship have had walls collapse not long after going into use. What PFI was able to achieve very successfully was to generate additional capital from non-governmental sources.

The fragmentation of the construction industry also extends to fragmentation of suppliers inside a PFI contract, and so the intended long term perspective does not always occur. A series of negative press stories points to some of these failures. The failure of PFI to reach sustainable outcomes perhaps demonstrates the pervasiveness of the effects of supply chain fragmentation.

Illustration 3: 'Vertical Integration of the Supply Chain'

One rather dramatic example of vertical integration in a supply chain is the SpaceX story. SpaceX negotiators had only 3 potential suppliers for lifting equipment into orbit, they were the: Russian; Chinese and European heavy lift rockets. The Russian was notably cheaper, and the limited supply of the market, (there is a larger demand for orbital lift but not at the price being offered). SpaceX, with its founder and owner Elon Musk, reportedly began negotiations with the Russian space industry noting that the cost of the materials in an orbital launch was 3% of the price, indicting there was a lot of profit (or waste) in the supply chain. As SpaceX is primarily interested in creating an opportunity to go to Mars in strength, they were able to promise future work. This was an important part of a negotiation, but with limited supply the Russian space industry, already cheapest, had no incentive to think about reducing profit margins. Realising this and realising any SpaceX ambition to lift a lot of equipment into orbit would flounder here, Elon Musk set about establishing a complete supply chain, and removing both margin and waste from that arguably complacent chain. Musk was able to consider this, because he had access to a huge personal fortune to set up the enormous credit required to do so. Normally such an undertaking might be limited to nation states.

In the U.K. sustainably differentiating building companies are obliged to address the problems in their supply chains by vertically integrating; doing all the work themselves. This usually means they set up a pre-fabrication factory and build to modular standardised units. A Leeds based example CITU also becomes the property developer, selling sustainable housing they have built, directly themselves.

These three illustrations serve to illustrate part of the structural factors facing construction companies that might seek to differentiate themselves as 'sustainable'. Of course any current contractor can offer to 'build any sustainable design', providing it is specified in the design, but price competition puts the building quality as risk. Even where there is a tier one intention,

they will still engage a fragmented set of suppliers who will also maintain price competition by making compromises with sustainable value.

In the U.K. Public sector clients are directed by Government expectations to make use of the HMTreasury guide to achieve 'value for money'. Often 'value for money' is interpreted as cheapest price. Both Gray (ref) and Flyvbjerg (2009) suggested that the approach to building business cases tended to lead to optimism bias, over promising benefits and under estimating costs. This may mean that many public sector projects, in particular, approach the procurement cycle with a need to reduce the forecasted capital cost. Thereby adding a further price reduction pressure to the mix.

These examples allow for the inference that the problems for sustainable construction lie more rigorously in the industry and their clients approach to procurement than in the availability of sustainable technologies, which it is argued above, might run contra to the interests of the contractor who may well need to create capital savings from the supply chain at the expense of more-sustainable building outcomes.

For Construction companies who would like to break this constraint and differentiate to a degree that sees them as being selected (or nominated) by clients, the options seem limited. Nevertheless attempts appear to be occurring. Clients might seek 'sustainability' but will prioritise capital cost, and even were they no tot, the contracting supply chain will do this to create further 'profit margin' from supply chain cost cutting opportunities.

To test whether the constraints of the current industry structure described here are pervasive and limiting of differentiation strategies for construction contractors/suppliers, the paper hypotheses that:

> H1 "Alternative Hypothesis" Contemporary attempts by construction firms to create strategic differentiation are merely further methods to improve price leadership competitiveness.
>
> H0 "Null Hypothesis" Contemporary attempts by construction firms to differentiate see differentiation that is not merely aimed at further price leadership.

METHODOLOGY

The preceding literature review selects evidence to affirm that existing approaches, in the industry, form effective barriers to differentiation strategies for construction firms and consequently more sustainability in construction. The design of the primary data is only informed by Porter's (1985) seminal work on 'competitive advantage' to arrive at a framework for construction firm analysis in an initial study. Porter (1985) proposed three models for analysing strategic competitive advantage offered by a firm, these are: The five forces model; the Generic strategies of cost leadership and differentiation and the value chain model. Applying these to the position posited in the introduction of this paper allows for a structured description of the current situation.

Generic strategies: Porter (1985) suggested that there are only two generic strategies behind competitive positioning. One was 'price leadership' to attract market interest because you were cheaper. And 'differentiation;' to attract market interest because you were 'different' in a way that represented desirable value, (over any cost leadership), to an extent that attracted a (possibly) niche market. Porter has argued that you can pursue one or the other and not both, 'quality at an affordable price is not price leadership but differentiation (on the basis of quality) he has argued. A differentiating construction firm would offer something different, (i.e. thermal performance) but at a price that *could* be beaten by a competitor who would build more cheaply but with not the thermal performance offered by the competitor.

Five forces: Porter's five forces asked strategic analysts to consider: competitive rivalry in the sector; Buyer power/leverage; supplier power/leverage; the threat of new entrants; the threat of substitutes. It is easy to imagine that the construction industry has high buyer/customer leverage and this may be part of its problem, because of the likely sensitivity of buyers to risking capital. Conversely supplier leverage is relatively low, and this also contributes to the sector. The barriers to new entrants is really quite low, especially at the tier two subcontractor and below levels of the supply chain. The threat of substitutes (new offerings that entirely replace the need for the existing service) maybe an unseen risk, but is not felt at the moment, it might be argued. The authors' imagine that the entrenched nature of contemporary construction procurement should mean that it is vulnerable to more radical substitution from new entrants.

Value Chain: Porter (1985) also developed the 'value chain' to link any analysis of the form's performance to the effect on how its market perceived the value, arguing that all activities in the 'value chain' (this could also be termed 'supply chain') should be linked to value adding activities as determined by the market (not the supplier). This model for analysis might be the most revealing of the detail of any individual firm's offering to the market. It can be argued that currently the supply or value chain in construction works to detract from the value that the client was anticipating, acknowledging that the client is complicit in this detraction. It is proposed that the Porter based analysis is applied to a selection of construction firms in Ireland and the U.K. who may appear to be pursuing a differentiation strategy. This may need to take the form of interviews in order to garner a qualitative insight.

Utilisation of these methods for analysing a firm's immediate market and industry structure, when applied the level of the firm, can offer insights into the chosen strategy and the strategy makers' perceptions.

This qualitative interview approach is not normally considered sufficient to allow for testing of a hypothesis. More usually hypotheses are tested using quantitative methods and closed questions. However it is possible to achieve quantitative hypothesis testing through a structured fixed method of interviewing, where the questions are consistent and this still allows the flexibility of being able to clarify answers. (Parahoo 1997 P.283, supported by Cartwright 1986 cited in Parahoo 1997). Waltz et al (1991) discussed the need for relatively homogenous groups to support this approach and Davis (1980) suggests this can be used where the vocabulary is common. Structured interviews may be more desirable to allow for some clarification to overcome any of Davis's issues, because construction issues will offer a common

language, the strategic management language may not. Prior to testing of the method, it is envisaged that there could be a pilot set of structured interviews based on Porter's methods for analysis and a follow up closed question survey.

SUMMARY

Differentiation strategies for construction companies face entrenched industry structured approaches that lead the industry towards 'price leadership' strategies that commoditise construction projects, leading in turn to quality compromises that do not necessarily serve sustainable outcomes. This means change to the industry and market may come in the form of new entrants that substitute the existing approach to procuring buildings. As greater sustainability in building is a pressing issue, and given that current approaches compromise this, firms that differentiate may be able to break away from current forms and differentiate to a point where they enjoy preferential single sourced procurement: True differentiation.

This issue of differentiation is of particular concern when it comes to improving sustainability outcomes for buildings, as sustainability is compromised by the existing price leadership approach.

Examples considered in this paper's illustrations, demonstrate the negative impact of 'price leadership' on sustainability outcomes; and how vertical integration has been developed as a response in other established markets and construction prefabrication; and also how PFI procurement, although designed to overcome some of these valued sustainability outcomes, was not successful in doing so.

This paper proposes a study to establish whether the assumptions behind this paper, that the construction industry is not successfully differentiating its services, can be proven.

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A FUTURE-PROOF CULTURAL HERITAGE: A HOLISTIC MIXED METHODS APPROACH

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Abstract

Mitigating environmental impacts has been a centre of attention for international commissions, legislative bodies and policy makers. The UK has signed up to an 80% reduction in carbon emissions by the year 2050 compared to 1990 baseline to meet this target at a national level. Energy used (primarily for heating) in the housing sector contributes 27% of all carbon emissions in the UK. Energy performance improvements of existing homes play a substantial role in the achievement of this national target, due to the low demolition rates and construction rates. The UK is facing a major challenge to address retrofit measures in this sector as it inherits the oldest and one of the most culturally rich yet most poorly performing housing stocks in Europe. The aim of this ongoing research is to propose a framework to intervene in traditional listed buildings to improve their environmental impact and shape a more future-proof heritage. A mixed methodology has been adopted using C19th case studies listed dwellings to investigate their current energy performance and the possible improvements in different scenarios of responsive and effective energy retrofits. A literature search, secondary data collection and analysis, visual and measured surveys, questionnaires, interviews, energy bills, meter readings, data logging, thermal-imaging and energy simulation are used to fulfil the research objectives. Providing a brief overview of this research methodology, the paper presents the detailed development of the methods utilised in this study up to date. It explains the measures, strategies and techniques, which were adopted to achieve simulation results of the status-quo energy performance of the selected case studies. This includes calibration of the models – used to ensure that the datasets collected or generated from different sources corroborate each other – and a brief report on the initial results of the current stage of research.

INTRODUCTION

Research background

The UK has committed to lowering carbon emissions by at least 80% by 2050 against 1990 baseline (Climate Change Act, 2008). 27% of all CO_2 emissions, in the UK, stem from the residential sector (BEIS, 2018), the main source of emissions from this sector being the use of natural gas for heating and cooking (BEIS, 2017). Approximately 75% of the housing stock will still be in use by 2050 (Wright, 2008), therefore, it can surely play a major role in mitigating climate change. Roughly one quarter of the total number of dwellings in the UK, are traditionalbuildings (STBA, 2012), built before 1919 with solid permeable walls (Historic England, 2011).

Most of these buildings are generally considered poorly performing (Boardman, 2007). About one quarter of this traditional stock is listed or within conservation areas (Bottrill, 2005). The

listing increases the challenges inherent in the energy upgrade of this part of the stock, as any retrofit measure needs to be weighed against the damage it may cause to its heritage value. In addition to the regulatory difficulties of intervening in listed buildings, the actual effect of such interventions on the historic fabric is not yet totally predictable (STBA, 2012). To be able to properly evaluate the outcome of any retrofit intervention on traditional listed dwellings (TLDs), more research is needed to thoroughly investigate their fabrics and understand how they behave. Responsible and effective retrofit solutions for these buildings will only be possible using a holistic approach, capable of balancing energy upgrades with potential impacts on the characteristics and heritage value as a result of such interventions in this part of the stock.

Aim and Objectives

This paper sets out to provide an insight into the methods utilised and a brief overview of the results achieved to date, in a research aimed at improving the environmental impact of TLDs, thereby reducing their energy consumption and carbon emissions to shape a more future-proof heritage. The main contribution of the study, which is reported in this paper, lies in the development and application of a mixed methods approach, which utilises multiple case studies, multiple units of analysis and multiple methods of data collection/generation to provide comprehensive, validated and holistic answers to the problem of retrofitting heritage dwellings. The methods here described are used to fulfil the first three objectives of this research: (1) to establish the most applicable method for carrying out energy analysis to best serve the purpose of this study; (2) to establish the actual energy use and thermal behaviour of the case studies (CSs) selected in their unimproved condition; (3) to devise a strategy to ensure that the data generation process is reliable, valid and replicable in similar or identical contexts.

Critical Literature Review- The Research Gap

A critical review of literature underlines all the phases of this study to aid in the definition of the research gap, research questions, aim and objectives, research design, methodology and methods. It evidenced how the use of dynamic energy simulation is extensive in research concerning the energy performance of buildings and proves to be the most applicable method also for the energy analysis required to fulfil the aim of this research (Panayiotou, 2014; Porritt, 2012 to cite some). The choice of CSs allows for a powerful validation tool for any research using simulation as main method because it consents triangulation of findings and a better reliability of the results generated. (Ascione et al., 2011; Blecich et al., 2016; Georgiou, 2015; Ingram, 2013; Mohammadpourkarbasi, 2015; Sahin et al., 2015). The studies conducted on heritage buildings constitute only a minority of the whole body of research about energy efficiency, often failing to take a comprehensive approach to the problem for historic/listed buildings. In this context, they have been mainly limited either to the investigation of potential retrofit interventions or of their heritage value and rarely taking account of both. However, a transdisciplinary and more multifaceted approach has been repeatedly called for as one potentially capable to aid in the decision-making concerning successful and conscientious retrofit measures for this part of the stock. Conspicuous is the body of research produced by Historic Scotland and Historic England on the subject of heritage buildings and energy efficiency. However, it mainly looks in detail at one or more elements of the external envelope like windows (Baker, 2008a; Wood at al., 2009), walls (Baker & Rhee-Duverne, 2013), specifically at envelopes U-values (Baker, 2008b; Baker, 2011), or investigates the potentialities of energy

simulation software for the evaluation of the building energy performance (Barnham et al., 2008; Heat et al., 2010; Ingram & Jenkins, 2013; Jenkins, 2008). Most of the studies that deployed a more comprehensive approach on this subject were often aimed at investigating one specific CS, frequently a public building (Ascione et al., 2011; Ogando & Fernandez, 2017; Sahin et al., 2015) therefore remaining limited in scope, applicability and generalizability. Little has been done on traditional heritage dwellings. The researches conducted on traditional dwellings by Ingram (2013) in Scotland and Moran (2013) in Bath, are rare but relatively good examples. However, they use limited number of cases and a validation strategy only based on energy consumption and only for part of the cases. More in-depth studies have been conducted on heritage dwellings in the Mediterranean area (Flores, 2013). However, the limits implicit in the geographic context, together with the similarity between the case studies investigated and the limited methods adopted, restrict the richness of data, narrowing the depth and breath of findings, which makes the generalization of them more difficult.

Finally, it is noted that, due to the wide range of uncertain input data and assumptions necessary to model traditional buildings, the potentiality of such models to accurately represent the thermal behaviour of the real building is strictly linked to the range of data used for calibration. Only a few researches have calibrated their results with real data but frequently limited to a single CS (Ascione et al., 2011; Ogando & Fernanez, 2017; Sahin et al., 2015). The review of literature showed a lack of in-depth studies on the subject of energy performance and retrofit interventions for TLDs in the South East of England where the materials and construction methods differ from elsewhere. It also evidenced the lack of a comprehensive validated, layered methodology, capable of integrating a whole set of methods for data collection, generation and analysis to apply to multiple cases of TLDs using multiple units of analysis in the context of the UK.

METHODOLOGY

Case study Design and Mixed Methods Approach

Centred on multiple CSs and using four subsequent phases of simulation, this research uses a combination of different methods of data collection, analysis and generation for the configuration of a baseline scenario of performance and of successive potential retrofit scenarios. CSs design has been chosen as it allows for a powerful validation tool for the energy simulation, consenting the calibration of the results using real data. A mixed methods approach has been adopted to couple the insights provided by quantitative and qualitative research and generate more comprehensive answers to the research questions (Johnson & Turner, 2003). Literature review, measured surveys, field observations, questionnaires, interviews, qualitative and quantitative thermo-graphic surveys, gas and electricity consumption monitoring, temperature and relative humidity (RH) data logging and energy simulations were used in combination for multiple CSs to facilitate the triangulation of findings and aid in the generalization of the results generated. The diagram in Figure 1 illustrates the research framework specifically outlined for this study, the methods of data collection, generation and analysis (in rectangles), the data gathered or generated (in bullet points), the sequential objectives achieved (Obj1-6), to provide an overall understanding of the research design.

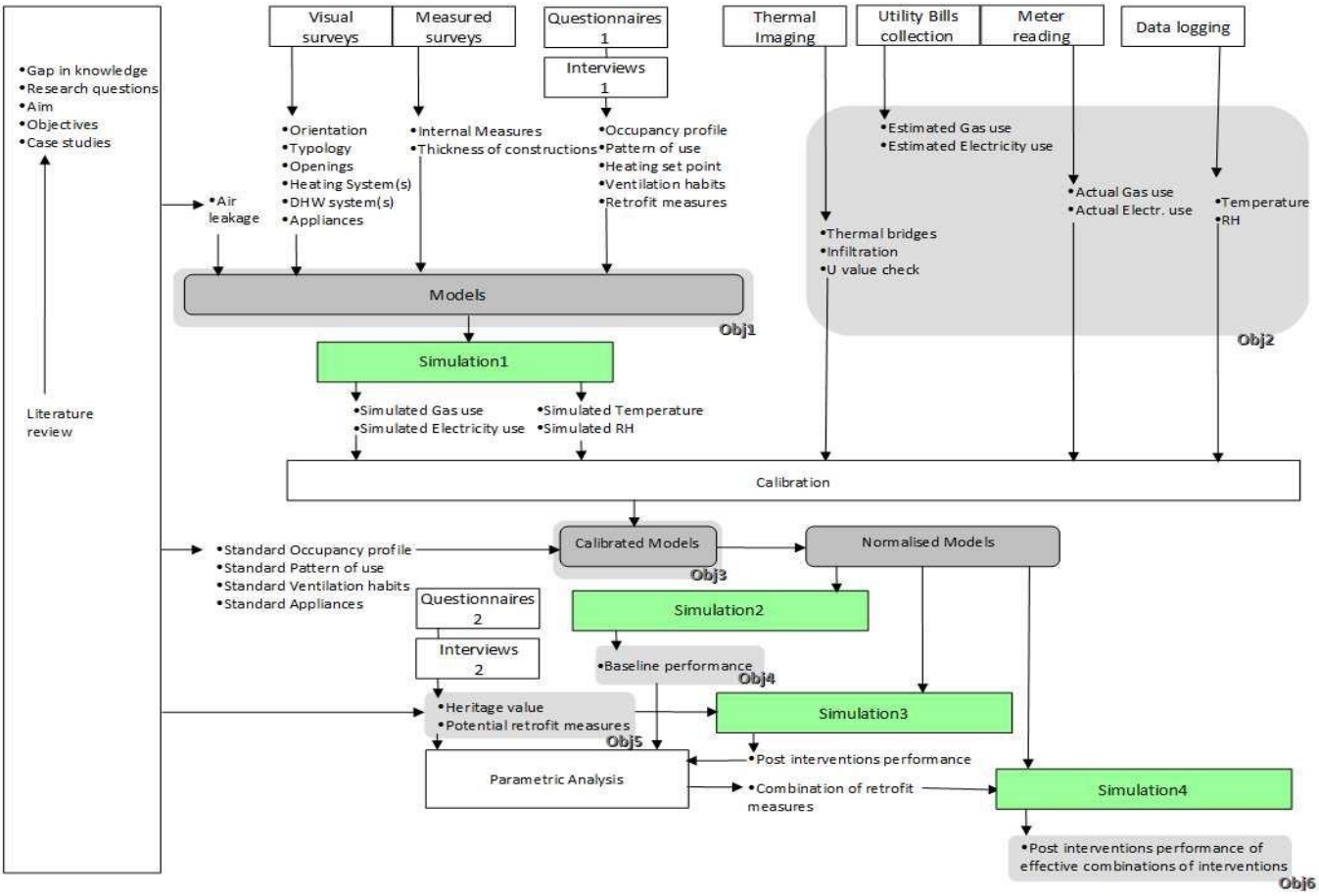


Figure 1. Research framework: methods (in rectangles), data gathered or generated (in bullet points), and objectives (Obj1-6).

The geographical location

The City of Brighton and Hove, centrally located within the South East coast of England, has been chosen as the geographical setting for this study due to the wide combination of different influential factors that it provides, proving to be an extreme case within the UK housing context. Almost 40% of the city's housing stock is traditional; a considerable proportion compared to the rest of Britain where traditional dwellings amount to approximately 25% (BPIE, 2011).

Many traditional dwellings in the city belong to the early 19th C, when Brighton, as many other coastal towns in the South East of England, was transformed into a seaside resort and embellished with unrivalled examples of Regency architecture (Antram & Morrice, 2008; Collis & Carder, 2010). These buildings are considered of great value as part of the town's historic heritage; hence comes the significance of the special care due to the preservation of their character. In fact, a substantial number of these traditional dwellings are listed. Most of these residential estates perform poorly (Brighton and East Sussex, 2008) because they were built at a time when very low living and energy standards were applied, when construction materials and technologies were limited and because of lack of investment in this sector.

Such setting for this study can give results that will likely prove to be easy to tailor or amend, to propose valid solutions for similar listed properties elsewhere in the South of England. The methodology proposed, once tested and proved successful in this setting, will also be valid to apply anywhere else in the investigation of retrofit measures for heritage dwellings.

Case studies selection

In this study, a multiple case approach has been considered the most suitable to enable cross case analysis and the triangulation of findings. Representative CSs have been selected using a non-probability sampling strategy obtained by carefully balancing purposive and convenience sampling approaches.

A first filtering was made to find potential participants adopting a convenient sampling technique that made use of emails (circulated within the University of Brighton mailing list) calling for all residents or owners of listed 19thC dwellings interested to take part in the study. The second part of the CSs search used purposive sampling. Invitation letters were delivered door to door in two main areas of investigation, Brunswick Town and Kemp Town. The case studies found there, are part of the first residential grand developments, built at the beginning of the 19th C. These two areas are located on the East and West of the city seafront respectively, containing the finest examples of Regency and early Victorian planning and architecture (Antram and Morris, 2008). The buildings typology, materials and constructions found there constitute an example followed for the rest of the century in the rest of the town and in the South of England.

To maximize what can be learnt from the cases, the decision concerning the number of dwellings to investigate was made upon the analysis of the variables expected in the population from which they are drawn in order to cover all the main characteristics of such population. Such variables can been described as follows: Period of construction (first or second half of the 19th C); Aspect (dual or single); Floor level (Lower Ground Floor, Ground Floor, Middle Floor, Top Floor); Orientation. Nine CSs were finally selected; they attempt to cover all the variables to investigate while being well distributed geographically in the two Eastern and Western areas of research. Therefore, although not intended to be a statistically representative sample, they allow detailed exploration of a snapshot of the C 19th TLDs typical of Brighton, as well as of many seaside towns in the South-East of England.

METHODS OF DATA COLLECTION AND GENERATION

The simulation software

The research methodology involves the use of dynamic energy simulations to identify, for each CS dwelling, the current energy consumption and carbon emissions. To take a decision concerning the simulation software to use, a literature search was conducted together with a desk survey of the available data and conversations with experts in the sector. IES-VE has been chosen as a suitable software to use in this research because, already validated by a number of studies, it allows the simulation of multiple case scenarios to be applied on the same model, hence the comparative analysis of the interventions; it is an application developed in the UK and its use is widespread in the country as well as around the world; it is easily manageable and offers a user-friendly interface.

Visual and measured surveys

Visual and measured surveys have been conducted for each CS. Each dwelling has been investigated in-depth in its orientation, typology, shape, measures, materials and construction methods, size and type of openings, heating and domestic hot water (DHW) system(s), domestic appliances, as a part of the in depth multi-units of analysis multi-case study approach chosen for this study. The collected data served as the first round of input in the energy simulation software to generate models as close to the actual dwellings as possible.

Questionnaires and interviews

Data about the building services, appliances, occupancy, pattern of use, temperature set points, ventilation habits and retrofit interventions already executed in the dwelling, was gathered for each CS using a questionnaire which was filled by the occupants on the day of the survey. On the same day a follow-up interview was conducted with the same participants. The questionnaires already filled in by them, constituted the basis for discussion and helped to identify issues and/or unclear points. The use of interviews was fundamental to guarantee that all questions were answered, to obtain therefore a full depth and range of information, to clarify any misunderstanding or provide additional explanations where required. The data gathered this way was also inputted in the energy simulation software to generate realistic profiles of use.

Utility bills and meter readings

The use of CSs presents an ideal opportunity to check the simulated energy consumption results against actual energy use data and therefore guarantee a higher reliability of the results generated through simulation. For this purpose, the annual utility bills were collected for each dwelling to be used as initial check of the results of the simulations.

The main household electricity and gas supply meter readings were then taken for all CSs for a period of at least one calendar year (the frequency of the readings – from every 2 months to a period up to 4 months – varies between the cases and depends on the participants actual availability or ease of contact). The simulation runs used the geometry and materials provided by the surveys and the profiles generated employing the detailed information collected through questionnaires/interviewees. Then the annual and sub-annual meter readings have been compared with the energy consumptions obtained from simulations to aid in their calibration.

Data logging

The actual conditions of the dwellings in use were measured and recorded for each CS for two periods (during the winter and summer season) of two months each time in two different rooms, to provide a triangulation of the results obtained from the simulations and contribute to a better reliability of the findings. Hobo data loggers (model Hobo UX100-03, Temperature and RH data logger) are deployed in this study. Such data loggers have been chosen as, widely used in research (Ahrentzen et al., 2016; Altan et al., 2013; Da Cunha, 2015 to cite some), they are affordable, low-maintenance, easy to operate and durable, compact instruments that

consume little power; they guarantee sufficient precision for the purpose of this study and have enough storage capacity for the periods of data collection intended.

Thermographic surveys

In this research qualitative thermographic surveys were undertaken for each CS dwelling to provide a better understanding of the composition of the thermal envelope (which, because of the private ownership of the flats, is not possible to investigate using intrusive methods) and to identify possible thermal bridges, or areas of ventilation losses. They aided in the refinement of the assumptions concerning air leakage and in the understanding of the thermal envelope of each dwelling. Quantitative thermography was also used as a quality check of the U-values calculated by the software.

PRIMARY DATA INPUT AND NEW DATA GENERATION

The dynamic thermal simulation operated involved creating 3D models of the CSs and their adjacencies, which were utilized to simulate the dwellings operation for a year making use of average local hourly climate data. The simulation calculates the energy used by the modelled dwelling through assessment of building operation, climate gains/losses as well as internal gains, solar & daylight penetration (IES, 2009). Therefore, the measured and visual surveys were used to compose the models, which were then added with use profiles based on the interviews and questionnaire surveys.

Once created the geometry of the dwellings and their adjacencies as well as the openings and shading devices use profiles, for each model were then defined specific building elements. Their constructions were based on the assumptions made using the measured thickness of the elements (whenever this measure was possible to take), on the visual and tactile inspection as well as on the literature review and conversations with experts about the typical constructions of the area at that time. The creation of specific constructions allowed the dynamic thermal models to generate U-values for the external envelope, to be used in the simulation of the current performance of the dwellings. These U-values will be modified, in the following stages of simulations, according to the new retrofitted constructions proposed in each stage. Finally, detailed specific data concerning the heating and DHW system(s), internal heat gains, occupancy and pattern of use of the heating system(s) and appliances (as provided by the surveys and questionnaires/interviews) were inputted for each model. For the air exchange rates, values of Air Changes per Hour (ACH) were inputted in each room template for each model, and modulated, within the values range found in the literature (CIBSE, 2015), depending on the exposition, the level of the flat, the age and type of windows. This data was then finetuned, in the calibration that followed, to aid in achieving correspondence between measured and simulated data.

MODELS CALIBRATION

The results attained through simulation have finally been checked against the data collected using bills, meter readings and data logging to calibrate the models and achieve results as close as possible to the actual energy consumption and thermal behaviour of the dwellings

investigated, thereby building confidence in the model's performance. Figure 2 describes the calibration process and the data collected and generated within it.

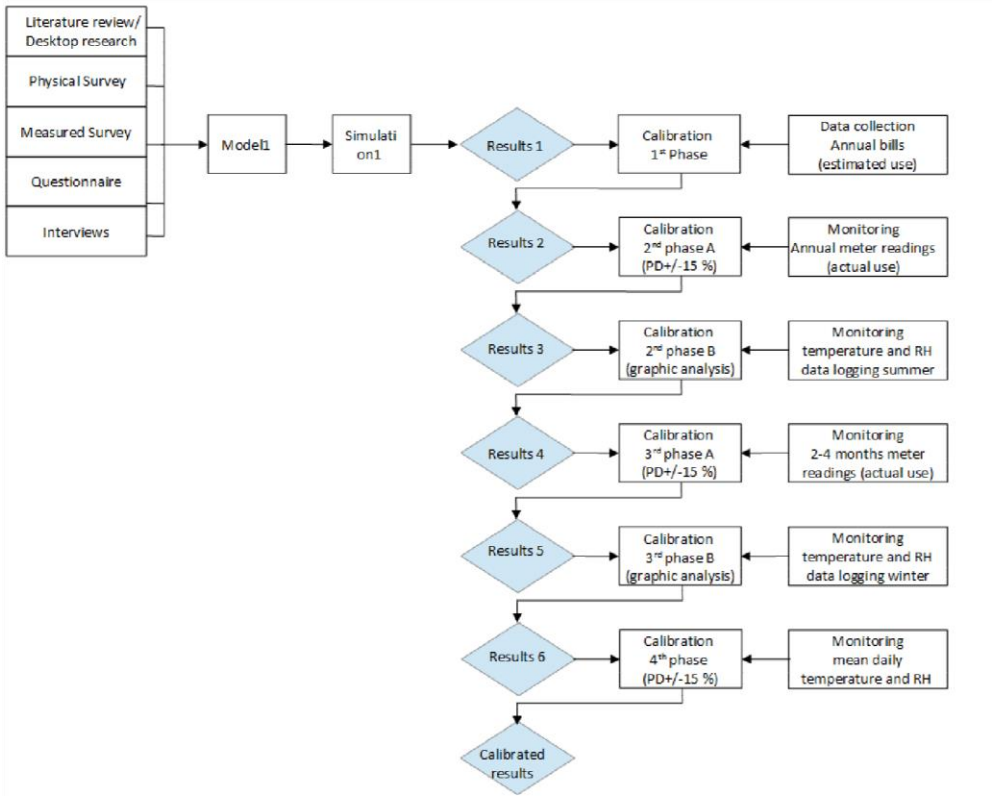
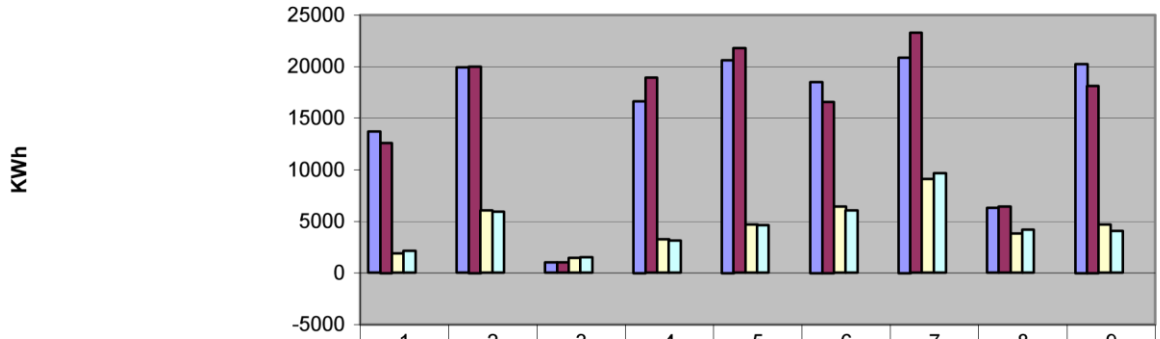


Figure 2. Flowchart of the calibrated simulation path as operated in the study.

The first set of energy simulations were initially checked against estimated energy use data provided by gas and electricity bills, to assess the capability of the models created to predict current energy use as well as energy and CO_2 emission savings in the later design stages. The meter readings of each CS were in the meanwhile carried out. This allowed a second calibration to be undertaken using actual data where a whole year energy use was accounted for. Percentage differences (PD) between simulation results and measured data have been calculated for gas and electricity over a period of one year. Values of the PD in the range of ±15% have been considered acceptable in accordance with previous research (Maamari et al., 2006; Reeves et al., 2012). The input values used in the first round of simulations for each CS were therefore fine-tuned, when needed, to calibrate the energy models with metered data and obtain results sitting within the acceptable range. A further calibration stage was performed using graphic analysis, once the first winter cycle of data logging was completed, comparing the temperatures and RH acquired by the sensors with the ones outputted from the dynamic simulations for the same time-period and for the same room. The objective was to validate the thermal behaviour of the models identifying if the graphs presented discrepancies or were reliable while also aiding in the understanding of the building envelope characteristics and of the behaviour of its thermal mass. To increase the reliability of the models a further calibration was performed using sub-annual energy data and assessing the PD with the energy consumptions outputted by the simulations for the same period. Part of the summer cycle of data logging is complete as well and for those cases the calibration has been integrated adding the graphic analysis of simulated and measured summer temperatures and RHs. Temperature and RH data will finally be calibrated to meet acceptable daily mean PD acquiring the specific annual weather file relative to the time-period in which the data logging was performed.

INITIAL RESULTS

To date, the iterative calibration process has been continued until the acceptable PD between measured and simulated annual and sub annual energy consumptions was met, and a good degree of similarity was seen between the measured and simulated (winter and summer) temperature and RH graphs. Seven out of nine CSs have already generated satisfactory results and are soon to be fully calibrated and ready to be used as baseline scenario for the application of retrofit interventions. Figure 3 shows the annual gas and electricity consumption monitored and simulated for each CS and the PDs achieved after this first stage of calibration. Figure 4 shows the graphical analysis conducted to compare simulated and monitored temperature and RH data for CS 2 (dining room), over two months in the winter period. A few discrepancies are still outstanding between these graphs. They might be caused by the difference between the averaged weather file used for simulation and the actual weather data pertaining to the monitoring period. Therefore, the next stage of calibration will be to make use of a weather file relative to the monitoring year aiming to exclude the variables potentially causing discrepancies as a result of weather. If it were proven that the weather is not the main cause of such differences, then other factors – pertaining to the building fabric, pattern of use, and heating system – were examined more confidently to find the source for such discrepancies.



	1	2	3	4	5	6	7	8	9
Gas Kwh/year Monitored	13645	19885	979.2	16608	20575.1	18500	20852.1	6299.81	20220
Gas Kwh/year Simulated	12572.2	19982.5	984.2	18881.4	21733.9	16567.2	23249.8	6397.8	18086.6
Electricity Kwh/year Monitored	1840	6000	1390	3218	4655	6375	9080	3820	4659
Electricity Kwh/year Simulated	2120.5	5881.7	1437.3	3079.1	4559.4	5988.6	9659.4	4183.8	4032.04
PD gas	-7.86%	0.49%	0.51%	13.69%	5.63%	-10.45%	11.50%	1.56%	-10.55%
PD Electricity	15.24%	-1.97%	3.40%	-4.32%	-2.05%	-6.06%	6.38%	9.52%	-13.46%

Figure 3. Graph and table showing the annual gas and electricity consumption (in Kwh) monitored and simulated for each CS (1-9) and the PDs calculated between them.

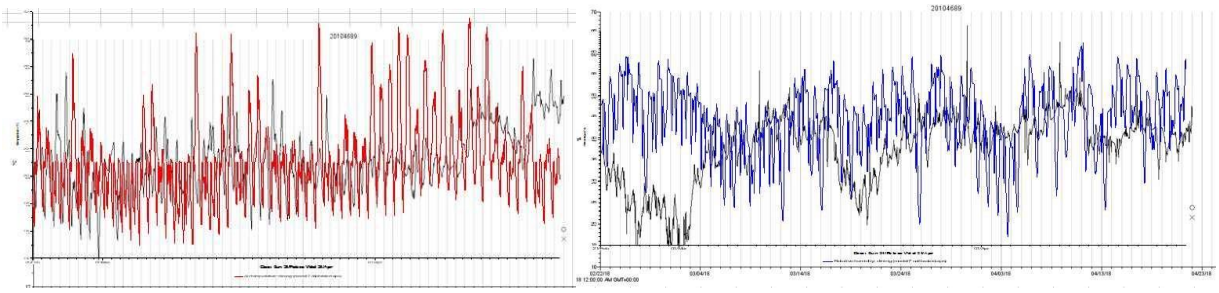


Figure 4. Graphs showing the simulated and monitored temperature and RH data relative to CS 2 (dining room), over two months in the winter period (in black: monitored temperature and RH data; in red: simulated temperature; in blue: simulated RH).

CONCLUSIONS

The results achieved at this stage of research provide good reasons to believe that the energy simulation tool deployed is capable of reproducing the actual thermal behaviour of the dwellings selected and to investigate their status-quo energy performance with a reasonable accuracy. This method is therefore also applicable in the following stages of research to simulate retrofit interventions in the chosen CSs and compare the energy performance post interventions to the baseline scenario.

A parametric analysis will finally generate combinations of interventions aimed at achieving the best possible balance between performance improvements, and conservation of heritage values. These combinations will be investigated in the last round of simulations to achieve the aim of the study: a framework of responsive and effective retrofit interventions for TLDs.

Two main limitations were faced in the methodology devised, namely the assumptions related to the U values and air leakage values of the envelopes. However, the U values generated by the software – given the materials build ups inputted – are triangulated with those generated by the quantitative thermographic surveys of the external walls and those given by previous research on similar dwellings (Baker, 2008b; Baker, 2011, IES, 2009; Ingram, 2013; Rye, 2010) to increase the reliability of such data. The air leakage values, taken from CIBSE (2015), can be checked using a blower door test once the necessary consent, from at least one of the participants, is obtained. A further confirmation of the validity of the used U values and air leakage rates will be provided by the satisfactory outcome of the calibration process.

The methodology devised and currently tested in Brighton is modular and customizable in order to be potentially extended beyond its context of origin and applied elsewhere for similar or identical studies.

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Energy

HVAC DUCTWORK DESIGN AND ITS IMPACTS ON LIFE CYCLE ANALYSIS OF A BUILDING

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Abstract

HVAC systems consume a large amount of energy within any building making it important for all HVAC engineers to understand the consequences of their designs. This paper assists in quantifying the effects of pressure drop in ductwork in terms of the life cycle assessment (LCA). Sizing ductwork is often done using a friction loss value that was historic for the design firm. As ductwork increases in size, noise and pressure drop are reduced while smaller ducts have an inverse effect, which can require the use of a larger fan and therefore more energy. This study shows that the production of ductwork has minimal effects when compared to the effects of fan operation. However, how ductwork is sized determines how much energy a fan will consume. The calculations used in this research show that utilizing low pressure or medium pressure ductwork is the most efficient use of materials as well as optimizing energy use when the system is in operation.

INTRODUCTION

An HVAC system is one of the largest consumers of energy in a commercial building. Engineers designing these systems have several factors that they must be aware of, and many building owners are asking that these designs maximize energy efficiency. Many studies look at the overarching themes of HVAC system energy efficiency, but most do not focus on the effect of the design of the ductwork system on the efficiency of the overall system. There are a range of industry standards that engineers follow to determine duct size and there is not a significant amount of data that determines the most energy conscious standard. In most universities in the U.S., engineering students are taught to keep their friction losses between .08" and .1" per 100 feet of ductwork. In practice, this standard is fairly consistent, but many engineers have differing opinions on which is optimal.

There is a minimal difference between these two values, but it is important to know how that difference impacts the rest of the HVAC system. In many consulting engineering firms, the design engineer uses .08", .01", or even .15" as their historic value used to start their basis of design for their ductwork system. Many engineers received this starting value from the previous engineer, and the values have been passed down from generation to generation without any

research or discussion on if these values are the most efficient. As duct size increases the amount of friction loss decreases, because there is more area for air to flow inside the ductwork. Conversely, when duct size decreases, the amount of friction loss increases because there is less space for the air to flow inside the ductwork. When a building's ductwork is oversized more energy is exerted to produce the ductwork, but when the ductwork is undersized the fan has to work harder to overcome the pressure drop. If ductwork is size incorrectly there can be a significant impact on energy consumption due to the fluctuating load on the fan, affecting the life cycle costs of the system. The purpose of this research is to determine if duct sizes have a direct effect on energy consumption of the system. This study analyzes the effects of pushing an equal amount of air through ducts that were sized using different friction losses. These ductwork simulations will be done on a case study building and the goal is to give HVAC engineers an understanding of how ductwork sizing affects the life cycle costs of the system in a building.

LITERATURE REVIEW

The need for life cycle analysis in HVAC systems is a relatively new concept in the design industry. For much of the past 50 years, HVAC system design and fan selection decisions were driven more often by first, rather than life-cycle, cost (Murphy, 2010). But many owners of buildings are becoming more concerned with the operational costs of their facilities, so engineers must be mindful of the life cycle costs of their designs.

The energy used by an HVAC system is a major factor in life cycle assessments of a building. HVAC systems and associated equipment consume a relatively large fraction of total building energy consumption, a significant portion of which is attributable to fan operation (Nassif, 2010). Since the sizing of the ductwork has a direct effect on the sizing and performance of the fans of an HVAC system, it is important to investigate how this affects the system. Many engineers use a rule of thumb for their pressure drop values in calculating their ductwork sizes. Uncertainty in HVAC system sizing exists as there is a lack of accurate information at the design stage to predict a building's peak load demand and not enough operational data to predict system operating cost and energy performance, so many engineers deal with this uncertainty by using a safety factor in their standardized sizing procedure, which tends to lead to excessive oversizing of the system (Huang et al., 2017). This oversizing will cause significant life cycle costs to the building and should be minimized.

One study stresses the importance of pressure drop in an HVAC system and how that affects system performance. The study analyzed the effects of dampers on pressure drop within the system, and although the study did not review the effect of ductwork size the theory is similar. The study found that the operation of economizer dampers when installed can cause significant energy consumption in fans if they are not operating properly due to high system resistance produced (Nassif, 2010). In this instance it is the dampers that are causing pressure drop that the fan must overcome, and it in turn is causing the system to use more energy. Conversely there are studies that focus on selecting the proper fan for an HVAC system in order to maximize energy efficiency. One such study reviewed the life cycle assessment of the air-handling units

for a building. The study concluded that a properly sized unit, even though it may be larger and require more material to create, will have less total energy consumption that a unit that is improperly sized (Nyman and Simonson, 2004). This is an interesting conclusion showing that a smaller unit may not be more efficient, but this study did not review any ductwork implications in their calculations.

Other studies analyze the fan selection in terms of air velocity and how that affects a HVAC system. One such study reviewed the efficiency of a commercial ductwork system by examining the effects of different air velocities. The study showed that reducing air velocity through a system by 10 percent would result in a 20 percent reduction in system static pressure, and since air power is proportional to pressure, this would equate to a 20 percent reduction in energy consumption (Mleziva, 2010). Again this study shows the importance of pressure drop in the system, but only looks at the theoretical savings on energy. Most of the literature on HVAC system efficiency and life cycle analysis focuses on HVAC equipment and system selection, but there are relatively few studies that do focus on ductwork. One study that reviewed the effect of ductwork sizing on life cycle assessment was conducted on residential applications. This study concluded that low- pressure ductwork generally yielded life cycle costs savings (Stephens, 2014). But unfortunately this is a residential application, and commercial applications are significantly larger and operate with different equipment using different velocities and pressure drops.

One study did review the effect of ductwork design on a commercial HVAC system, specifically using a Variable-Air-Volume (VAV) system. This study looked at common variations in ductwork installations to try and determine the effects of those variations. An orthogonal test matrix was used and it found that for square diffusers, the energy required to distribute air post VAV unit could be more than doubled by variations in the installation (Landsberger et al., 2008). Although this study did the most in terms of quantifying the energy usage, it focused on ductwork installation variation and not the design of that ductwork, nor did it review the system in terms of life cycle analysis of the HVAC system.

RESEARCH METHODOLOGY

In order to determine if the sizing of HVAC ductwork has an adverse impact on the energy use of a building, a case study building was identified. For this study the proposed Milwaukee School of Engineering (MSOE) Engineering and Innovation Center was used. This project is a 4-story academic facility with a basement-level parking garage. The building consists of offices, classrooms, and laboratories and is approximately 232,000 sf. According to ASHRAE standards, this building will require 10 cubic feet per minute (CFM) of air per person for ventilation standards (ASHRAE, 2013). This results in 20,000 CFM of outdoor air required to meet the ventilation loads for this application. A dedicated outdoor air system (DOAS) was selected to supply 100% of the outdoor air for the building.

In order to most accurately determine the best friction loss for sizing ductwork, this study analyzed the impacts of low pressure ducts sized at 0.08" and at 0.1" WC per 100 feet and then

compared to high-pressure ducts that were sized at .15" and .25" WEC per 100 feet. Ducts were sized to be as square as possible since this allows for optimal airflow within the system.
For this study it was determined that a 100-foot linear run of ductwork directly connected to the DOAS unit would be analyzed. This section of ductwork is large enough to show the cost and environmental impacts of the system, and can be scaled for larger buildings. The section of ductwork used is shown below in Figure 1.

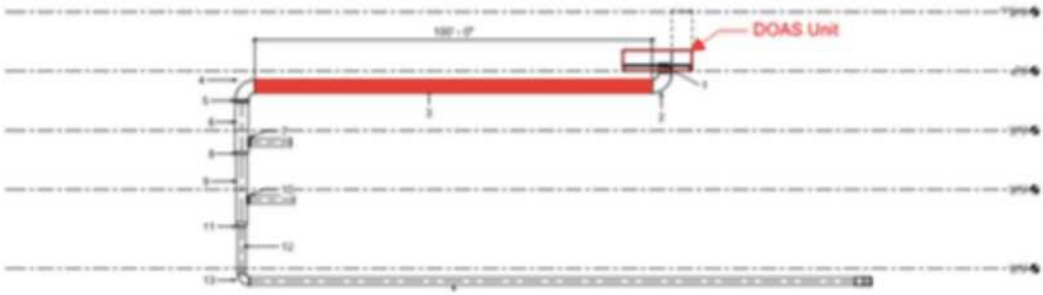

Figure 1 - Ductwork Section Used for Analysis

This section of ductwork was sized using the ASHRAE Standard 62.1 (ASHRAE, 2016). The fan size was determined for each of the ductwork scenarios of both low-pressure and high-pressure applications. The fans used for this study were from the manufacturer Daiken, and the sizing was completed using the fan curves found on their corporate website. The energy use of the fan in each of the ductwork scenarios will be compared to analyze its total life cycle impact.
In order to fully analyze the life cycle impact of the ductwork sizes, several factors were identified. First the material cost of each ductwork system was calculated. Next, the installation cost of each ductwork system was determined. And finally the annual electricity cost to run the DOAS unit was calculated. These items determine the total cost for each system. Finally the life cycle costs of these systems were analyzed using a ten-year life cycle period for both the ductwork and the DOAS unit.

RESULTS

The calculations to determine ductwork size were complete and the results are shown for the low-pressure ductwork in Table 1, and the results for the high-pressure ductwork are shown in Table 2.

Friction Loss	Width (IN)	Height (IN)	Length(FT)	Area (SF)	Weight (LBS)
0.00	44	40	100	0.0163	805.53
.1”	40	38	100	0.0152	747.97

Table 1 - Low-Pressure Ductwork Characteristics

Friction Loss	Width (IN)	Height (IN)	Length(FT)	Area (SF)	Weight (LBS)
.15”	40	34	100	0.0144	709.6
.25”	34	32	100	0.0128	632.86

Table 2 - High-Pressure Ductwork Characteristics

Once the sizes of each ductwork system were determined it was possible to associate a material cost as well as an installation cost for each system. These costs were identified using the 2018 National Plumbing & HVAC Estimator on a per pound basis (Thompson, 2017). The corresponding material and installation costs for each ductwork system are shown in Table 3.

Friction Loss	Material Cost per LB	Material Cost	Install Cost per LB	Installation Cost
0.08”	$1.88	$1,514.40	$1.82	$1,466.06
0.1”	$1.88	$1,406.18	$1.82	$1,361.31
.15”	$1.88	$1,334.05	$1.82	$1,291.47
.25”	$1.88	$1,189.78	$1.82	$1,151.81

Table 3 - Material and Installation Costs of Ductwork

It is assumed that all four systems would utilize the same DOAS system so the cost of the DOAS unit was removed from the study, since it is constant for all systems. But the pressure drop created by each system is unique, as is the fan energy needed to overcome that pressure drop. The overall pressure drop of each system was calculated using ASHRAE standards and fans for the DOAS unit were selected using the fan curves provided by Daiken (Daiken, 2018). It was assumed that the DOAS unit would run continuously throughout a year and the energy costs per Kilowatt Hour (KHW) charged by the local energy provider is $.10 (We Energies, 2018). Table 4 the results of the fan energy used for each ductwork system is shown.

Friction Loss	Static Pressure	BHP	Efficiency	KWH/Year	Cost per KWH	Energy Cost
.08”	0.993	2.5	70%	23,339.14	$0.10	$2,375.92
.1”	1.176	2.75	70%	25,673.06	$0.10	$2,567.31
.15”	1.454	3.1	70%	28,940.54	$0.10	$2,894.05
.25”	2.109	4.75	70%	44,344.37	$0.10	$4,434.44

Table 4 - Fan Energy

With all of the relevant costs calculated a life cycle analysis was performed using a 10- year life cycle for each system. The initial cost of the material and installation of the system was compared to the energy used each year by the system. The high-pressure system with a friction loss of .25" was used as the baseline of comparison for the other systems in terms of both payback period and total cost over the 10-year span. The results of the analysis are found in Table 5.

Friction Loss	Initial Cost	Annual Energy Savings	Payback Period	10-Year LCA
.08"	2980.46	2058.12	1.448146852	17600.74
.1"	2767.49	1866.73	1.482533628	15899.81
.15"	2625.52	1539.99	1.704894188	12774.38
.25"	2341.59	0	0	0

Table 5 - Life Cycle Analysis

DISCUSSION

It is not surprising that low-pressure ductwork is larger in size than high-pressure ductwork because of the pressure drop of each system. Because of this, the material costs for each system increases as the friction loss gets lower. And because the ductwork is larger the installation costs for this ductwork is also larger. If one were to look at only the material and installation costs, high-pressure ductwork would be more cost effective to use and would have a larger impact on the life cycle costs of the system.

Overall the cost of the material and installation of the ductwork between a .08" friction loss ductwork system and a .25" friction loss system in this case study is $638.87. This is also a one-time cost savings since this only includes the manufacture and installation of the system. In the life cycle view of a building, this is an insignificant savings.

But when factoring in the effect of having high-pressure ductwork has on the size and efficiency of the fan supplying the air it changes the results of this assessment. The annual energy savings of the .08" friction loss ductwork system over the .25" ductwork system is $2,058.12. That applied over a 10-year span also taking into account the first cost of the manufacture and installation of the ductwork translates into a savings of $17,600.74.

It is clear from the results that it is not just the ductwork size that is driving the life cycle impact of the system on a building. It is the fan energy consumption that is the primary factor in the environmental and financial concerns. But there is a direct relationship between the friction loss value used to design the ductwork and the effect in size of the fan used in the HVAC system, which then driving the energy use of the system.

All engineers are taught the importance of sizing fans correctly due to the amount of energy they can consume. But what may not be obvious is that duct sizes are equally important because of their impact on the fan choice. The results of this study on a 100- foot section of ductwork show a significant impact on the life cycle analysis of a building, if a similar study were to be conducted on the entire building worth of ductwork and fans the impacts would be significantly greater.
Often engineers are under pressure to decrease the size of the ductwork in order to minimize

the ceiling space needed on a building project. Many owners of building projects focus only on the up-front expense of the systems used in the project, but there can be lasting effects of decisions made from that perspective. Engineers should inform their clients that minimizing ductwork size cause higher fan sizing and operation, and significantly increase the annual expense to run the HVAC system.

CONCLUSION

The primary conclusion of this study is that HVAC engineers should be cautious when sizing HVAC ductwork for buildings. Fans are an important part of a building HVAC system and consume significant amounts of energy. The current trend in building construction is to attempt to design buildings that are more energy efficient and overall more sustainable. Engineers need to be aware of the impacts of their decisions on how they design HVAC ductwork on their projects in terms of the energy usage.

As previously mentioned, many engineers pass down their friction loss factors from generation to generation without much thought to how this affects the HVAC ductwork system. The intent of this study is to inform engineers, both young and old, of the impacts of their choices in this regard. This study shows that the impacts of analyzing the HVAC ductwork sizing can have a profound impact on initial cost as well as life cycle impact on a building.

The 100-foot span of ductwork analyzed in this study is a small portion of what would normally make up a commercial HVAC system. The results of this study can be scaled to reflect the impacts on a large commercial project. The impact of one engineer being misinformed on how to properly size ductwork instead of using previous generic rules can have a large effect on the system. If HVAC engineers were to consider their old habits and evaluate a HVAC ductwork system in more detail instead of using their generic rules, perhaps they could prevent unnecessary equipment upgrades and produce another means of reducing energy consumption.

Further studies could be conducted on an entire building system to validate the results of this study. This analysis would include how different ductwork fittings affect pressure drop and fan energy use. The angle of transitions, frequency of elbows, and length of straight ductwork between fittings could yield some interesting results on what would be considered best practice for routing ductwork through a building to maximize energy efficiency.

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A COMPARISON BETWEEN THERMOSTAT AND THERMOSTATIC RADIATOR VALVE SETPOINT TEMPERATURES IN UK SOCIAL HOUSING

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Abstract

In the UK, in centrally heated dwellings, space heating is commonly controlled by a whole house thermostat as well as thermostatic radiator valves (TRVs) fitted on individual radiators. TRV settings define a setpoint temperature at which the radiator is switched off, in order to regulate zonal temperatures. This paper presents an analysis of the TRV setpoint temperatures which occupants' select in living rooms and main bedrooms and provides a comparison between these and the whole house thermostat setting. The work capitalises on primary data from a socio-technical household survey undertaken in a sample of social housing in Plymouth, UK during 2015. The mean reported TRV setpoint temperature in the living rooms (n = 144) and bedrooms (n = 120) were 23.4°C and 22.1°C respectively. This result confirms that occupants prefer cooler conditions in their bedrooms and also suggests that occupants are actively using their TRVs to zonally control their heating at home to maintain comfortable thermal conditions and reduce their heating energy demand. The results also indicate that occupants' thermostat and TRV setpoint temperatures vary according to their household and motivation, behaviour and perception characteristics. The mean reported thermostat setpoint temperature was 20.7°C for those who reported a living room TRV setting and 20.9°C for those who reported a bedroom TRV setting. This result suggests that there may be a misunderstanding of the purposes of the whole house thermostat and the individual TRVs within a central heating system. Variations in occupant heating control behaviour have an impact on occupant comfort and household energy use. The results of this study have significant implications for the planning and implementation of energy efficiency measures, behaviour change interventions as well as the design of heating controls.

INTRODUCTION

Energy use in domestic buildings accounts for 29% of total UK energy consumption and around two thirds is used for space heating (Department for Energy and Climate Change (DECC), 2013). Domestic space heating accounts for 11% of the nation's greenhouse gas emissions (Department for Energy and Climate Change (DECC), 2012). Reducing heating energy use in homes is therefore essential if the UK is to achieve its commitment to reduce national carbon emissions by 80% of 1990 levels by 2050 (HM Government, 2008). The three key avenues that are being explored in order to achieve this target are (1) the refurbishment or replacement of the existing housing stock (Hamilton *et al.*, 2016), (2) decarbonisation of domestic heating supply (Energy Technology Institute, 2015) and (3) social interventions, i.e. occupant behaviour change, to encourage more efficient use of energy (Lopes, Antunes and Martins, 2012).

In the UK, over 75% of the current UK building stock will still be in use in 2050 and the stock is only being expanded at a rate of 1 – 2% per year (Ravetz, 2008). The main issues with the existing housing stock are poorly performing solid walls, single glazed windows and uninsulated roofs and floors and are responsible for a significant amount of wasted heat (Loveday and Vadodaria, 2013). In response to this and in line with the commitment to meet carbon reduction targets, the UK social housing sector in recent years has embarked on a large scale programme of thermal upgrades, as well as the installation of more efficient heating systems and controls. Regarding social interventions, it has been demonstrated that there is a considerable variation in energy consumption between "identical" dwellings and this is due to how the dwellings are used (Andersen, 2012). Occupant behaviour has been very well noted to significantly affect a building's energy consumption (Hoes *et al.*, 2009; Yoshino, Hong and Nord, 2017).

Space heating is an important aspect of household energy consumption and occupant comfort. Central heating, which allows households to simultaneously heat all the spaces in their dwelling is now found in over 90% of UK homes (Department for Energy and Climate Change (DECC), 2013). The predominant fuel is gas, which is more efficient than solid fuels, and has resulted in greater carbon efficiency for heating. A basic central heating system consists of a central boiler, a pump and individual radiators located in multiple spaces throughout the dwelling. Most central heating systems will also have some level of controls – a full set of central heating controls consist of a central timer, a whole house thermostat and thermostatic radiator valves (TRVs). Since 2010, two zone heating has been mandatory for all new dwellings which are not open plan (HM Government, 2010), however this is not obligatory in existing dwellings. A central heating system that complies with Building Regulation Part L1B will have the full set of controls. Even with the widespread ownership of central heating systems in UK homes, it is reported that about 70% of the housing stock do not have the full set of heating controls specified in the building regulations and 4% do not have any controls at all (Heating and Hot Water Task Force, 2010). A dwelling with no thermostat may result in excessive room temperatures and with no TRVs a lack of zonal temperature control. Where heating controls are available, they will have a significant influence on a dwelling's space heating energy demand (Shipworth *et al.*, 2010; Fabi, Andersen and Corgnati, 2013; Huebner *et al.*, 2013; Beizaee *et al.*, 2015; Jones *et al.*, 2016; Cockroft *et al.*, 2017).

Multiple factors have been found to influence space heating preferences (setpoint temperature and heating duration) and a detailed international review and discussion of these factors have been presented by Wei et al. (2014). Amongst these factors is the type of heating controls installed in the dwelling (Guerra Santin, Itard and Visscher, 2009; GuerraSantin and Itard, 2010; Shipworth *et al.*, 2010; Consumer Focus, 2012). Heating controls such as TRVs have the potential to reduce space heating energy use, as heating demand temperatures in less frequently or unoccupied rooms or rooms requiring cooler temperatures can be reduced or turned off completely. However, it has been noted that simply providing central heating controls does not necessarily result in dwellings being heated in ways that reduce energy consumption and carbon emissions (Shipworth *et al.*, 2010). To support decisions to help reduce space heating energy demand in social housing, it is important to understand how social housing tenants use their available heating controls. There is currently a lack of empirical data underpinning the recommendations for space heating energy reduction policies.

This paper presents an analysis of social housing tenant's choice of TRV setpoint temperatures in living rooms and main bedrooms and provides a comparison between these and the chosen whole house thermostat setting. The work capitalises on primary data from a socio-technical household survey undertaken in Plymouth, UK during 2015.

The role of TRVs for energy demand reduction

A TRV controls a single radiator and it is used to keep a room at a different temperature to the rest of the dwelling. It offers a cheap and easy way of providing zoned temperature control. They usually have a dial marked with a * and numbers from 0 to 5 or 0 to 6. The * represents a minimum temperature which is usually 6.9°C for frost protection and the number settings correspond to setpoint temperatures from 0 to 28°C. Where the TRVs have settings up to 6, the maximum temperature for each setting is lower compared to TRVs with settings up to 5 only. When the central heating boiler is in operation, TRVs sense the air temperature and regulate the flow of hot water to the radiator, allowing for zonal temperature control. They do not control the boiler operation and will only control zonal temperature if a lower temperature setting, compared to the whole house thermostat setting is selected. Allowing rooms that are not often or are unoccupied to be heated to cooler temperatures or not heated at all reduces the difference between internal and external temperatures, thus reducing the rate of heat loss and heating energy demand.

The energy saving potential of zonal temperature control has been demonstrated in several previous studies (Meyers et al., 2010; Beizaee *et al.*, 2015; Cockroft *et al.*, 2017). In the US, Meyers et al. (2010) showed that 6.2% of total primary energy is wasted from heating or cooling living rooms during the night and 9.7% is wasted from heating or cooling bedrooms during the day when the spaces are unoccupied. In a modelling study of a pair of identical 1930s dwellings, one equipped with simple TRVs and the other equipped with programmable TRVs, Beizaee et al. (2015) showed that the dwelling with programmable TRVs used 11.8% less gas compared to the dwelling with the simple TRVs. With the programmable TRVs, the rooms were heated only when occupied and with the simple TRVs, the rooms were heated whenever the boiler was on. Furthermore, a 0.6°C reduction in mean indoor temperature was observed when programmable TRVs were used. In another modelling study, Cockroft et al. (2017) investigated the potential energy savings between non-zoned (heating controlled by whole house thermostat only) and zoned conditions (heating controlled by thermostat and programmable TRVs). The study demonstrated that significant energy savings in the order of 8% to 37% can be achieved by adopting a multi-zonal control strategy where both time and temperature in individual rooms are controlled.

This paper aims to provide an insight in to the use of whole house central thermostats and TRVs in UK social housing. The paper responds to a gap identified in the literature, the lack of evidence as to how occupants are using TRVs to regulate their thermal comfort as well as their heating energy demand. The analysis could enable social housing providers and the government to target energy efficiency measures, particularly social interventions (i.e. behaviour change) at those dwellings and households where their impact may be most beneficial, as well as to inform the design of future domestic heating controls.

METHODS

The data analysed in this paper are derived from a socio-technical household survey undertaken as part of the European Horizon 2020 research project: Energy Game for Awareness of energy efficiency in social housing communities (EnerGAware) which was conducted in the city of Plymouth, UK (*EnerGAware*, 2016). The social housing investigated in this study are managed by the housing association DCH (formerly Devon and Cornwall Housing) who are also a partner of the project. Plymouth was the case study city chosen as social housing accounts for 20.1% of the city's housing stock, one of the largest proportions in the UK (Office of National Statistics, 2012). A detailed description of the socio-technical household survey is provided in Jones et al. (2016). In summary, the socio-technical survey was administered to 2,772 social houses (social rented and shared ownership) in Plymouth. The survey was occupant self-reported through either a paper-based postal survey or an online survey administered through the online survey software, SurveyMonkey and was conducted in May 2015. The survey contained 68 standardised closed questions. Out of all the surveys administered, 537 responses were received, giving an overall response rate of 19.4%. The socio-technical survey provided occupant reported winter living room and bedroom TRV settings and the whole house thermostat setpoint temperature as well as household characteristics (e.g. household size and composition, health of HRP [1] and households with disabled members) and motivation, behaviour and perception characteristics (e.g. affordability of energy bills, worry about energy bills, understanding and perceived control of energy use at home, perceived ability to save energy at home, heating related behaviours and dwelling occupancy pattern).

The occupant reported TRV settings were converted to their corresponding setpoint temperatures by referring to the manufacturer's specifications. The survey responses along with the whole house thermostat setpoint temperatures and the converted TRV setpoint temperatures were input, cleaned and organised in an IBM SPSS Statistics 24 database for analysis.

RESULTS

Of the 537 households responding to the survey, 29 reported bedroom TRV settings of 0 and one reported a * setting. These were excluded from the analysis as they indicate that the radiators were not in use. 144 provided a living room TRV setting as well as a thermostat setting and 120 provided a bedroom TRV setting as well as a thermostat setting.

Table 1 shows the overall mean living room and bedroom TRV and thermostat setpoint temperatures. The upper and lower 95% confidence intervals (95% CIs) for the data are presented to demonstrate the distributions of setpoint temperatures reported, as well as the extreme values reported in the coldest and warmest homes. The standard deviations (SD) are presented to demonstrate how much the reported setpoint temperatures differ from the mean value.

The mean reported TRV setpoint temperature was 23.4°C in the living room and 22.1°C in the bedroom and the difference in these mean temperatures was significant ($p < 0.01$). This implies

[1] The Household Representative Person (HRP) is the individual that is taken to represent that household. In this study it describes the person that completed the survey.

that there is a preference for cooler conditions in bedrooms and shows that social housing tenants use their TRVs to zonally control temperatures in different rooms. The 30 households who reported turning their bedroom TRVs off (0 or * setting) further supports this finding. The mean whole house thermostat setting was 20.7°C from those who reported a living room TRV setting and 20.9°C from those who reported a bedroom TRV setting. These thermostat setpoint temperatures are consistent with the 21°C recommended by the World Health Organization (WHO) as a comfortable indoor temperature, and to prevent potential health effects (World Health Organization, 1987).

Table 1 Reported mean TRV and whole house thermostat setpoint temperatures

		Whole house thermostat setpoint temperatures (°C)		TRV setpoint temperatures (°C)	
	n	**Mean (95% CI)**	**SD**	**Mean (95% CI)**	**SD**
Bedroom	120	20.9 (20.4, 21.4)	2.7	23.4 (22.8, 24.0)	4.4
Living room	144	20.7 (20.2, 21.2)	2.8	22.1 (21.1, 22.7)	3.6

In both the living rooms and bedrooms, the mean TRV setpoint temperatures were higher than the mean thermostat setpoint temperatures. From the 144 households that reported living room TRV settings, 94 (65%) had a TRV setting higher than their thermostat setting, 16 (11%) households had the same setting for their TRV and thermostat and 34 (24%) households had TRV setpoints lower than their thermostat. Where the TRV setpoint was higher than the thermostat, the TRVs were on average set to 5°C higher than the thermostat setting, with the average TRV set to 25°C and thermostat to 20°C. In the households where the TRV setpoint was the same as the thermostat setpoint, the setpoint temperature was set to 20°C. In cases where the TRV setting was lower than the thermostat, the average difference was 3°C, the average TRV setpoint was 20°C and thermostat was 23°C. From the 120 households that provided bedroom TRV settings, 56 (47%) had higher TRV setpoint temperatures, 16 (13%) had the same and 48 (40%) had TRVs set lower. Where the thermostat setting was higher than the TRV setting, the average setpoint temperatures were 20°C and 26°C respectively. In households where both settings were identical, the setpoint temperatures were 21°C and in households with lower bedroom TRV settings, there was an average 4°C difference, with the average thermostat setpoint temperature set to 22°C and the bedroom TRV set to 18°C.

Table 1 in the Appendix presents the variations in reported mean thermostat setpoint temperature and living room and bedroom TRV setpoint temperatures in relation to household and motivation, behaviour and perception characteristics. In most of the groups, the TRV setpoint temperatures were higher than the thermostat setpoint temperatures. However, the differences between the mean thermostat setpoint temperatures and the mean TRV setpoint temperatures were not significant.

In relation to household characteristics, the thermostat setpoints were always lower than the living room and bedroom TRV setpoints regardless of the education level of the HRP, the presence of disabled members in the household, whether households were in receipt of welfare benefits or their satisfaction with life in general. Regarding motivation, behaviour and

perception characteristics, again thermostat setpoints were always lower than living room and bedroom TRV setpoints regardless of occupants' perception of their affordability of energy bills, their understanding of how their home uses energy, and their heating behaviour (i.e. their use of doors and thermostats during the winter).

There were some instances where the TRV setpoint temperatures were lower than the thermostat setpoint temperatures. In households where the HRP was unemployed, the living room (21.6°C) and bedroom (21.0°C) TRV setpoints were lower than the thermostat settings (23.0°C). Where the HRP reported bad health and visiting the GP 7-12 times per year, the bedroom TRV setpoints were lower (Health: 21.3°C; GP visits: 20.0°C) than the thermostat setpoints (Health: 21.8°C; GP visits: 21.2°C). The analysis showed that households that indicated that they do not worry about their energy bills and they do not think about how they can save energy had lower bedroom TRV setpoint temperatures than their thermostat. Households that strongly agreed to having control over how much energy they used and those who disagreed to not being able to save any more energy also had lower TRV setpoints in the bedroom. In relation to not being able to save any more energy, households that tended to disagree also had lower TRV setpoint temperatures in the living room. Regarding heating behaviours, households that indicated that they sometimes close windows when the heating is on and they very occasionally turn the heating off when no one was at home, set lower TRV setpoint temperatures in the living room and bedrooms than on their whole house thermostat.

DISCUSSION

The findings reported in this paper show that social housing tenants' space heating behaviour (i.e. use of TRVs) varies according to the room within their dwelling. The current study indicates that bedrooms are generally cooler than living rooms and not all bedrooms are heated; 29 respondents reported a 0 TRV setting and 1 bedroom was only heated when the bedroom temperature falls below 6.9°C (frost protection setting). By comparison, all the respondents who provided a living room TRV setting indicated that their living rooms were heated.

In general, the mean TRV setpoint temperatures reported in this paper (living room - 23.4°C, bedroom – 22.1°C) are higher, than what is assumed in BREDEM-based models where the temperature in the living area is set at 21°C and in the rest of the dwelling (including bedrooms) is set to 18°C (Anderson *et al.*, 2002). The results are however consist with the BREDEM assumption that living room temperatures are higher than that in bedrooms. Also, comparing the current results from the whole house thermostat (20.7°C and 20.9°C) with the 21°C used by BREDEM, suggests that the value is appropriate for living areas.

Regarding the mean thermostat setpoint temperature selected by these social housing tenants, the results obtained (20.7°C and 20.9°C) are similar to the 21.0°C recommended by the WHO as a comfortable indoor temperature and to prevent potential negative health effects (World Health Organization, 1987). It is also similar to the whole house demand temperatures reported by Huebner et al. (2013) (20.6°C), Shipworth et al. (2010) (21.1°C) and Kane et al. (2015) (20.9°C). Overall, the high level of agreement between the findings of the different studies is noteworthy given the different methods (temperature monitoring and self-reported) and

different samples (owner-occupied, privately rented and social rented). The thermostat demand temperatures are within 0.5°C.

The work presented here shows that there is a variation in how occupants use heating controls in their homes. The whole house thermostat controls the overall heating system and the TRVs control temperatures in individual rooms. In rooms where the TRV setpoint temperature is higher than the thermostat setting, the TRV setpoint temperature becomes redundant as it will not be reached before the heating is turned off by the thermostat setpoint. Using TRVs to set cooler thermal conditions in different rooms has the potential to reduce space heating energy demand. From the sample presented in this paper, 65% of the households reported higher living room TRV settings than their thermostat setting. This observation was evident regardless of most household and motivation, behaviour and perception characteristics. This finding suggests that: (1) occupants may prefer warmer conditions than what the overriding thermostat permits, (2) perceived thermal comfort may be more important to occupants than actual thermal conditions, and (3) residents may not understand the role of TRVs as part of the home heating system and thus their energy saving potential.

Regarding household characteristics, households with unemployed members and households with couples with dependent children had lower TRV settings compared to the whole house thermostat settings. This was seen in both the living rooms and the bedrooms. In these households, members may be trying to save money by adjusting their TRVs. In the households with unemployed members, this finding also gives an indication of a possible impact of household income on space heating preferences. The lowest thermostat settings were in homes where the HRPs considered their general health in the last 12 months as very bad. Bad health may limit their potential to work, hence reducing their household income. Alternatively, low thermostat setting indicates cooler thermal conditions in the homes, which may contribute to the bad health of the HRP. The effect of household income on TRV setpoint temperatures was not directly investigated, as the survey did not ask respondents to report their annual household income. Previous studies have identified significant effects of income on space heating behaviour (Hunt and Gidman, 1982; Sardianou, 2008) The question of household income was considered too sensitive as the study focussed on social housing residents who typically are a low-income group.

Regarding motivation characteristics, only occupants who reported that they strongly disagree to often thinking about how their home uses energy and those who reported that they tend to disagree with not being able to save anymore energy had lower TRV settings compared to the thermostat setting in both the living rooms and the bedrooms. In the remainder of the characteristics, TRV settings were higher than thermostat settings in all the groups. These findings suggest that there may be a lack of understanding of the use of these heating controls, particularly as a potential to save energy and reduce energy bills. Heating is used to provide a comfortable thermal environment, hence achieving thermal comfort may be more important to householders than having lower temperatures or shorter heating periods in order to save energy. Although it has been shown that the use of TRVs as a heating control can decrease heating energy demand (Beizaee *et al.*, 2015; Cockroft *et al.*, 2017), it is also noted that the savings are not necessarily achieved unless the user has knowledge about the operation of the

control mechanism (Shipworth *et al.*, 2010). Perhaps, the householders are not aware of how this additional heating behaviour can help them to reduce their heating energy demand.

The usability of heating controls also influences their use (Meier *et al.*, 2010). Although TRVs are easy to use, the settings are displayed as numbers ranging from 0 to 5 or 6 with little indication of the corresponding temperatures, whereas the settings on the thermostat are shown in temperatures. If householders are not able to make the link between TRV setpoint temperatures and thermostat setpoint temperatures, the energy saving opportunities could be missed.

The findings suggest that although social housing tenants are using TRVs to zonally control temperatures in their homes, they may not be aware of the energy saving potential of these heating controls and are currently missing out on reducing their heating energy demand and consequently their heating bills.

The results obtained in this study provide a useful insight in to occupant heating preferences. However, there are limitations in the method which may have implications on the study findings. The results are based on relatively small sample sizes (living room TRV setpoint temperatures and whole house setpoint temperatures for 144 homes and bedroom TRV setpoint temperature and whole house setpoint temperatures for 120 homes) from a single UK city and therefore extrapolating the results to the wider population is not appropriate. A larger national-scale study of TRV and thermostat settings would be a valuable extension to the current work and could also be used to validate the findings of the current study. The reliability of self-reported data provided by survey participants is most often limitation. Without the presence of an interviewer, the respondent may not fully complete the questionnaire before submission (as seen in participants providing living room TRV setting and not bedroom TRV setting). Also, providing heating settings at one point in time is also a limitation as occupants may change the setpoint temperatures may change over time. To the author's knowledge, Andersen's et al. (2011) study in Denmark which developed a custom monitoring device, is the only study to provide direct measurement of TRV setpoint in homes. With the rapid development of 'smart' internet-connected thermostats and TRVs, which allow users to control their heating via a website or on their smart phones, data on space heating preferences will become increasing available for further research in this field. This could however take many years.

CONCLUSION

Based on self-reported thermostat and TRV settings, an analysis of mean setpoint temperatures in relation to household and motivation, behaviour and perception characteristics have been presented. The findings show that the mean whole house setpoint temperature is similar to the WHO recommended comfortable indoor temperature and is also in agreement with findings from previous studies. The findings regarding zonal temperatures, by the use of TRVs, showed that the social housing tenants in this study preferred different thermal conditions depending on the room, i.e. cooler conditions in the bedroom than in living rooms. This finding is in agreement with BREDEM-based models and with findings from previous studies and suggests that occupants are actively controlling their zonal temperatures to ensure their thermal

comfort. However, the mean TRV setpoint temperatures obtained in this study were found to be higher than the assumed input values typically used for energy modelling. The mean TRV setpoint temperatures were also higher than the mean thermostat setpoint temperature, implying that the participants in this study are not using these controls to reduce their heating energy use. The findings from this study provide further insight into social housing tenants heating behaviours and have implications for housing providers, heating technology providers, the government and commercial organisations that implement energy efficiency measures. The study findings suggest that people may not understand how their heating system controls actually work and therefore interventions aimed at reducing heating energy use in homes as well as the design of heating controls, should first help occupants to understand and operate their heating controls efficiently.

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Appendix

Table 1 Reported mean TRV and whole house thermostat setpoint temperatures according to household and motivation, behaviour and perception characteristics

	Living room			Bedroom		
Household characteristics	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**
Duration of tenancy						
<3 years	44	20.8	23.3	41	21.0	22.3
3-5 years	20	21.3	23.7	18	21.7	22.6
6-10 years	27	20.5	24.0	21	20.8	21.9
11-20 years	34	20.4	23.5	26	20.6	22.2
20+ years	19	20.7	22.2	14	20.1	19.4*
Household size						
1	75	20.7	23.2	62	20.8	21.7
2	45	20.7	23.8	37	20.8	22.1
3	12	21.3	23.5	8	23.0	22.0*
4	5	20.2	22.0	5	20.2	21.6
5+	7	19.7	24.3	8	20.4	22.3
Household composition						
One person	68	20.6	23.4	62	20.8	21.7
Couple, no dependent children	44	21.1	23.6	32	20.8	21.7
Couple, dependent child(ren)	4	20.1	20.0*	5	23.2	22.4*
Lone parent, dependent child(ren)	5	21.6	22.4	5	19.8	20.8
Highest qualification of HRP						
O'Level, GCSE, NVQ Level 2 or equiv.	25	21.1	24.2	24	21.1	21.3

A'Level, NVQ Level 3 or equiv.	28	20.8	24.6	28	20.9	22.6
Degree level or above	22	20.8	22.5	18	21.0	22.1

	Living room			Bedroom		
Household characteristics	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**
Another kind of qualification	12	22.0	23.5	10	22.1	23.0
No qualification	28	20.1	22.9	20	20.5	21.9
Employment structure						
Employed	26	20.5	23.9	19	20.5	21.8
Unemployed	5	23.0	21.6*	4	23.0	21.0*
Retired	33	21.0	23.1	27	20.9	21.6
Student	2	15.5	27.0	1	19.0	16.0*
Household in receipt of welfare benefits						
Yes	59	21.0	24.0	48	21.1	22.8
No	72	20.4	23.1	65	20.7	21.6
Health of HRP						
Very good	26	20.6	22.9	26	21.1	21.7
Good	41	20.6	23.1	33	20.7	21.2
Fair	33	20.6	24.6	28	20.6	23.1
Bad	20	21.9	24.0	17	21.8	21.3*
Very bad	17	19.5	22.9	11	20.1	23.5
Number of GP visits in a year						
0-1	32	20.3	23.2	30	20.7	22.7
2-4	35	21.2	24.1	31	21.5	22.3

5-6	14	20.9	24.1	12	20.8	22.7
7-12	14	20.7	22.9	10	21.2	20.0*
12+	9	22.4	23.6	7	22.3	24.3
Household with disabled members						
Yes	53	21.1	21.9	53	21.1	22.0
No	67	20.7	22.1	67	20.7	21.8
		Living room			**Bedroom**	
Household characteristics	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**
Satisfaction with life						
0-3 (Dissatisfied)	20	21.1	22.4	11	21.6	23.1
4-6 (Neither dissatisfied nor satisfied)	47	20.9	24.2	44	20.9	22.5
7-10 (Satisfied)	76	20.4	23.2	64	20.6	21.3
Motivation, behaviour and perception characteristics						
Affordability of energy bills						
Very easy	14	20.5	23.6	13	20.9	21.7
Fairly easy	35	20.9	23.1	28	20.6	20.6
Neither easy nor difficult	53	20.7	23.7	46	21.1	22.6
Fairly difficult	29	20.2	23.3	23	20.3	21.7
Very difficult	11	21.9	22.7	8	21.6	22.3
I am worried about my energy bills						
Strongly agree	18	20.6	24.0	15	20.9	23.3
Tend to agree	53	20.8	23.7	44	20.7	21.8
Neither agree nor disagree	26	19.8	23.1	19	20.3	22.8
Tend to disagree	19	21.2	23.3	17	21.1	20.9*

Strongly disagree	21	21.8	22.8	20	22.0	20.7*
I don't understand how my home uses energy						
Strongly agree	11	21.7	24.6	9	22.3	23.8
Tend to agree	37	21.1	23.5	30	20.6	21.6
Neither agree nor disagree	31	20.1	24.0	25	20.7	22.6
Tend to disagree	23	20.9	23.8	19	21.1	21.4
Strongly disagree	28	20.8	22.2	27	20.9	21.3
I often think about how my home uses energy						
Strongly agree	41	21.0	23.5	30	21.4	22.5

	Living room			Bedroom		
Household characteristics	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**
Tend to agree	67	20.5	23.8	59	20.7	21.8
Neither agree nor disagree	16	21.1	23.0	16	20.5	21.6
Tend to disagree	6	18.3	21.7	3	21.0	24.0
Strongly disagree	8	22.9	22.5*	7	22.6	18.9*
I have control over how much energy is used in my home						
Strongly agree	36	21.3	22.1	28	21.3	20.6*
Tend to agree	54	20.3	24.0	45	20.3	22.5
Neither agree nor disagree	29	20.8	22.8	23	21.4	21.1*
Tend to disagree	13	19.8	24.5	12	21.7	22.5
Strongly disagree	5	22.4	25.2	6	21.7	23.7

I am not able to save anymore energy						
Strongly agree	15	20.6	23.7	11	21.1	22.7
Tend to agree	46	20.5	24.1	37	20.7	22.1
Neither agree nor disagree	38	20.6	23.3	31	20.5	21.7
Tend to disagree	18	20.6	22.8*	19	21.0	20.7*
Strongly disagree	11	22.3	22.0	10	22.5	21.4*
I make sure the curtains/blinds are closed when the heating is on in the evening						
Always	82	20.8	23.3	67	20.9	21.8
Often	35	20.3	23.8	28	20.8	21.5
Sometimes	15	20.7	24.4	14	20.8	23.3
Very occasionally	3	22.0	24.7	3	22.0	22.7
Never	7	21.4	21.1*	6	21.2	22.0
I make sure the curtains/blinds are open when the sun is shining in winter						
Always	103	20.9	23.6	87	21.1	22.0
Often	27	19.8	23.2	20	19.7	21.4

	Living room			**Bedroom**		
Household characteristics	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**
Sometimes	8	21.1	24.8	7	21.1	24.0
Very occasionally	3	19.7	17.3*	3	19.7	17.3*
Never	1	26.0	24.0*	1	26.0	28.0
I make sure the windows are closed when the heating is on						
Always	106	20.7	23.8	87	20.8	22.3

Often	24	19.7	23.5	21	20.2	21.1
Sometimes	10	23.0	20.4*	9	22.8	19.8*
Very occasionally	2	23.0	22.0*	1	26.0	28.0
I closed the doors between rooms						
Always	49	20.6	22.9	38	20.6	22.0
Often	24	21.8	23.8	20	21.9	22.0
Sometimes	26	20.5	23.8	27	20.9	21.4
Very occasionally	13	19.8	24.6	10	20.1	23.6
Never	26	20.3	23.6	20	20.7	21.9
I wear very warm clothes in winter so I keep the heating low o r off						
Always	60	20.8	23.4	48	21.1	22.5
Often	42	20.2	22.8	34	20.1	20.5
Sometimes	24	19.9	25.1	24	21.7	23.1
Very occasionally	9	23.5	23.8	5	21.7	21.2*
Never	8	21.3	21.8	8	20.4	22.0
I change the temperature on my thermostat						
Always	64	20.8	23.8	55	21.1	21.8
Often	29	20.7	22.8	26	20.7	21.5
Sometimes	32	20.8	23.9	24	20.7	22.6
Very occasionally	6	18.4	23.0	5	20.5	20.8

	Living room			**Bedroom**		
Household characteristics	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**	**n**	**Mean thermostat temp. (°C)**	**Mean TRV temp. (°C)**
Never	10	20.9	22.6	7	20.9	24.0

I turn the heating off when no one is at home						
Always	97	20.8	23.4	81	21.0	22.2
Often	20	20.2	24.3	18	20.3	21.4
Sometimes	16	19.9	23.5	13	20.0	22.2
Very occasionally	4	23.5	22.0*	4	23.5	17.0*
Never	6	21.3	23.0	3	21.3	24.7
I turn off the heating in rooms that are not nor	*mally used*					
Always	56	20.5	22.7	35	20.7	21.9
Often	25	20.3	23.2	22	20.3	19.7*
Sometimes	17	20.1	24.7	19	20.6	22.5
Very occasionally	14	21.9	23.3	13	21.7	21.1*
Never	23	21.5	24.2	22	21.5	23.5
I adjust the temperature on my radiators						
Always	40	20.5	23.2	31	21.4	22.0
Often	30	21.3	22.2	24	21.3	20.3*
Sometimes	35	20.6	23.4	31	20.5	21.2
Very occasionally	16	20.3	25.1	13	20.4	22.8
Never	18	20.9	25.0	16	20.8	24.9

***** TRV setpoint temperature is lower than the whole house thermostat setpoint temperature

RE-WIND: ARCHITECTURAL DESIGN STUDIO AND THE RE-PURPOSING OF WIND TURBINE BLADES

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Keywords: design studio, wind turbines, reuse, circular economy.

Abstract

This paper discusses the opening moves of an international multidisciplinary research project involving researchers from Ireland, Northern Ireland and the US, aiming to address the global problem of end-of-life disposal of wind turbine blades. The problem is one of enormous scale on several levels: a typical 2.0 MW turbine has three 50m long blades containing around 20 tonnes of fibre reinforced plastic (FRP). It is estimated that by 2050, 39.8 million tonnes of material from the global wind industry will await disposal. Whilst land-fill is the current means of disposal, the nature of the materials used in the composite construction of wind blades (glass and carbon fibres, resins, foams) means it unsustainable. Hence, the project sets out to deploy innovative design and logistical concepts for reusing and recycling these blades. The project begins within an innovative joint design studio, staged between Queen's University Belfast and the Georgia Institute of Technology, where architecture students will, within the highly-constrained contexts of the blade properties and the potential reuse sites, systematically generate, filter, and prototype a selection of proposals, reusing the decommissioned wind turbine blades in buildings, infrastructure, landscape, and public art. The paper analyzes the potential and challenges of considering this highly constrained and yet multidisciplinary problem within the context of a Masters level Architecture studio. The paper concludes with an analysis of how outcome-driven design problems challenge traditional design studio cultures, acknowledging the need to make processes and ideas more explicit in order to categorise, analyse, rank and refine proposed architectural solutions.

INTRODUCTION

This paper discusses the opening moves of an international multidisciplinary research project involving researchers from Ireland, Northern Ireland and the US, aiming to address the global problem of end-of-life disposal of wind turbine blades. The overarching research problem is one of enormous scale on several levels: a typical 2.0 MW turbine has three 50m long blades containing around 20 tonnes of fibre-reinforced plastic (FRP). Wind blade designs for off-shore turbines are however expected to continue to increase in scale. The largest blade to date is 88.4 meters in length, (i.e 4 tennis courts long) and it is expected that this will become the norm as the demand for wind energy increases. With a life span of 20-25 years for each wind blade, this means that by

2050, approx. 40 million tonnes of material from the global wind industry will await disposal (Liu, P & Barlow, C.Y 2017; Bank et al 2018).

Currently wind blades at their end-of-life, can be recycled and/or disposed of in a range of ways. These include: the predominant strategy, landfill, where the whole resource goes to waste; various form of incineration: some of which may recover energy and/or some materials (defined as quaternary recycling (Bocken et al 2016)) chemical processing (defined as tertiary recycling) that recovers some materials but in a downgraded form; and finally, mechanical (mostly in the form of secondary recycling) which separates the resins from the fibres for use as filler reinforcement material i.e a downgrading process. All processes have negative implications: environmental, economic and/or as potential health hazards. The material nature of the blades' composite construction (glass and carbon fibres, resins, foams) means they are extremely difficult to 'deconstruct' in order to allow the materials to be reclaimed and reused.

Windblades are made primarily from glass fibre fabrics, with some carbon fibre in the high stress areas of longer blades. The fabrics are infused with a thermos-set resin, typically vinylester or epoxy. To provide high flexural stiffness with low weight, the skins and webs are typically produced as sandwich panels, with cores composed of balsa or foam (Figure 1). The balsa or foams are cut with a CNC router to conform to the airfoil shape, and the entire preformed package – fibre layers and cores – are placed in a single-sided mold and resin infused to form one massive monocoque structure. The resulting unitized structure is a significant advantage for manufacturing and promotes a long fatigue life for the blade, relative to other blade material systems. But of course the corollary of this unique and fiercely integral characteristic of windblades is that once constructed they are extremely difficult to deconstruct into constituent materials or smaller parts for 2nd / 3rd life purposes.

These end-of-life challenges have received very little attention to date (Ramirez et al 2016). Yet given how sensitive the general public have been around the resultant noise and ecological damage of wind turbines, there is a pressing need to develop sustainable end-of-life strategies that underpin rather than undermine wind-power's green credentials. Whilst policies may evolve over time to encourage manufacturers to develop circular strategies, research projects such as this lead the way within present contexts, deploying informed creativity to imagine future solutions.

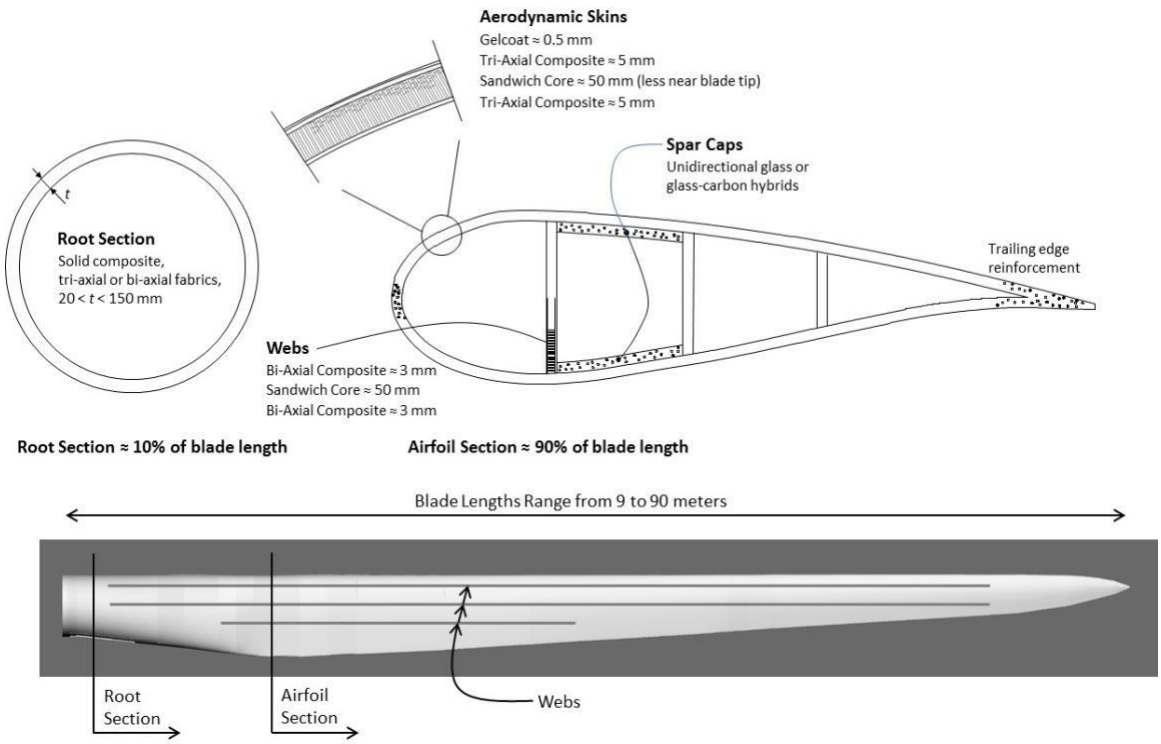

Figure 1: Typical blade construction (adapted from Gentry et al. (2018)).

The wider research project sets out therefore to deploy and marry innovative design and logistical concepts for reusing and recycling these blades. In other words: the project team understands decommissioned wind blades as being a significant, large scale and growing global resource of materials and components – conceptualised by the project team as 'a New Forest'. The questions that then emerge are: what is the nature of the structure, materials, and components. How best might those materials be deployed in other applications? And can this done in ways that is environmentally cognisant of the contexts (social, cultural, economic) in which the wind-blades are currently located, and, of the potential new applications and location of markets for 2nd (and 3rd etc) life products?

Obviously the challenge is much greater than a three year project can fully address, but we have a diverse, international team of researchers and stakeholders, who understand that the process of generating, critiquing, prototyping and testing possible solutions will, in and of itself, provide a process template for future solutions for repurposing large-scale infrastructure materials and systems.

This paper focuses on the early stages of the research project where it is proposed to use masters level design studios in Schools of Architecture at both Queen's University Belfast and Georgia Institute of Technology to generate and test initial ideas on how to repurpose wind blades. This is

a rather unique beginning to what looks like an engineering problem. The paper will therefore discuss the value of bringing a design approach to the project. A fundamental research question for this paper is: How can a masters-level design studio bring value to this Research Project?
To answer the question the paper will address: The Nature and Value of Design, especially in relation to Issues of Circular Economy; The significance of the students' role in such a research project; and the challenges to the normative format of Design Studio, when organized to be in direct support of a research project. We will then outline four strategies that have been identified and developed to respond to the challenges and hence deliver value to the research project; concluding with closing remarks on what this project might offer beyond a potential solution to the problem of repurposing wind-blades, and its significance.

The Nature and Value of Design

In his seminal book: *How Designers Think: The Design Process Demystified*, it takes Lawson to Chapter 3 to concede that he can find no one definition of design that is 'useful' – definitions are either so specific that they are quickly outdated or so generic that they are of little practical use. Instead he attempts to understand design by looking at how it is practiced over time and by whom. He charts the shift from craftsman as designer, where designing and making were synonymous and attuned to 'use', to the point where design professionals sit remotely both from the maker and the end-user. Cross (2001) also writes how researchers have tried to 'scientise' design, by trying to capture and pin it down to rationalized design methods, which ultimately were too inflexible and consequently ignored by practitioners. Contradicting Cross are design methodologies based on strict analytical protocols such as those described by Pahl and Beitz (1984), which are clearly appropriate in design of devices and systems where the relationship between part, assembly, and function can be clearly delineated. Recent thoughts on the role of designers align less to problem solving and more to *curating* complex 'messiness' into some semblance of structure - aware that with more time, more resources, a different team, in another context, the processes would vary and the design outcomes would differ.

Where research is engaged in analysis (sometimes implying deconstruction), design is concerned with anticipating and constructing new futures informed by knowledge of old patterns. It's this ability to future forecast and respond holistically to context and resources that makes design a natural bedfellow for sustainable circular practices – at least, potentially. Those involved in driving forward the Circular Economy have recognized this potential and the urgency in helping designers to develop more appropriate skills.

'Design will play a key role in the transition to a circular economy. We need to educate and inspire the design industry to take up this challenge.' Sophie Thomas RSA REPORT 01 (2013)

A recent collaboration between the Ellen McCarthy Foundation (A UK based organization promoting an economy that is restorative and regenerative by design) and IDEO (a global design firm) led to the production of a comprehensive online resource, 'The Circular Design Guide'. The Guide is targeted chiefly at product design and business however its tool kit and language provides a useful resource for and influence on this project.
The problem of using traditional design skills in a re-purposing project is described by Ali (2017) as one that requires both the understanding of *design process* as well as the *design of processes*, wherein the designer not only has empathy for the artifact but also for the logistics, workforce, and constraints imposed by the re-use problem. Ali cites the need for a decision support framework, to be developed and used by the designer as a means to judge the success of the re-purposed design proposal. Blizzard and Klotz (2012) provide a review of whole-systems design frameworks that are directly relevant to the development of a circular economy for wind turbine blades. According to Ali, in adapting architectural design problems to the circular economy, the focuses becomes more on means (processes) as opposed to goals (aspects of the designed artifact). This is necessary because of the material and geometric constraints applied by the product re-use scenario, which in the case of windblades, is evident.

Aside from the fact that designers can generate propositions for the re-use and repurposing of materials and components into second- and third-life products, designers also possess strong 2-D and 3-D graphical skills. These skills allow them to communicate holistic, complex ideas and strategies in ways that are remarkably accessible to a wider range of audiences, allowing a diverse research team to interact *through* images, models and prototypes rather than remain within linguistic and jargon-based silos.

The Design Studio

As stated earlier, the initial stages of the research project will be run through a Design Studio (Sept-Dec 2018). It's here that the research team's understanding of the problem will be presented and further evolved through design. The QUB students will generate as many ideas as possible and these will gradually be reduced in number over a semester by a process of testing, reflecting and critique, including the critique of design tutors, researchers and wider stakeholders. The outcomes will then be passed to Georgia Tech where they will be prototyped at part and full scale and further assessed through structural testing, and economic and life cycle analysis. The design studio is the perfect environment for this activity for a number of reasons:

Design Studios are peer- and interactive-learning environments that are framed around projects. Typically students are given project briefs set by Design tutors that mimic real life conditions. They respond to these projects over a few weeks, though at postgraduate level this is typically sustained over one semester. Students work alone and/or in teams but the intention of the designated studio space is to provide an environment where novice designers work and learn alongside one another.

This occurs through a continuous process of informal feedback on their investigations and propositions, supplemented on a weekly basis with more formative feedback and critique from design tutors and invited experts.

The Design studio is regarded as a safe space where students are encouraged to test the edges of a problem. Experimentation is not only permitted but also expected – since by pushing at the edges of an idea students are simultaneously learning and testing their own skills, knowledge and values.

The process in the Design Studio is a rigorous one where students are encouraged to work iteratively and to move through and test ideas across a range of scales. Circular design draws heavily on this skill of moving between scales, but it also challenges us to not only consider physical scale i.e. product, buildings, landscape, infrastructure, but also to consider the systems they sit within i.e. manufacturing, economic and social (EMF and IDEO, 2017).

Aside from setting the pedagogical framework for the design studio, the Design Tutors are there to encourage students to experiment with a range of tools, tactics and methods to enrich and develop their own praxis. In addition their role is to help students to either converge their thinking to deliver outputs within given timescales, or indeed to open up their thinking to further explore alterative possibilities. The same brief will draw as many different design outcomes as there are students – no one answer is 'right' , though some are 'better'. However the aim of design studio teaching is ultimately to ensure that the students develop their own voice and most especially, a strong critical engagement in their own work, since this is the fundamental driver for their future design practice: '*Our role is not to help people towards our understanding of architectural practice, rather, their own'* (Morrow 2015).

So the design studio, when properly structured, is a place where high levels of creativity are mixed with rigorous critique; where multiple voices are supported and yet where delivery of tangible outcomes is assured. To paraphrase Masschelein, an educational philosopher, the design studio is a unique space that creates a gap between what is possible and what is actual (Masschelein 2011).

The Students' Role

Placing the initial design idea generation phase within a postgraduate design studio allows us to capitalise on the creative capacity of architecture students. We intend to assign this research problem to around 15 students over an 11 week period. The studio provides a design resource that we would not be able to afford by other means, but the challenge is to ensure that not only does it deliver products to our research project but also that the learning experience of the students is a full and positive one. To that end, we draw on the team's established experience of running live projects as part of the design curriculum (Morrow & Brown 2012).

"A live project comprises the negotiation of a brief, timescale, budget and product between an educational organisation and an external collaborator for their mutual benefit. The project must be structured to ensure that students gain learning that is relevant to their educational development." Anderson and Priest, 2016

The students' role is also much more fundamental, on two levels. Firstly the project is better served by having as varied a range of ideas at the outset as possible; and as previously described: the design studio and the tutors are purposefully there to support diversity of outcomes. A professional design office would be more likely to converge on a narrower bandwidth of ideas that map to their expertise and profile. Secondly, by involving students we follow one of the areas of recommendations set out in the RSA's 2013 Report on design in the circular economy, which is to skill up the Design Industry, preparing future generations of designers by integrating design for circular economy and systems thinking into the design curricula and creating moments of cross-curricular learning, connecting designers with engineers, material scientists, etc.

Design Studio Challenges

In advance of the design studio running we are mindful that there are conventions within Architecture Design Studio Culture that might offer some resistance to the project. The four key areas are mapped out below.

1. Scope and Scale. Architecture Design Studios can focus on a range of scales – from large to small: urban design, landscape, buildings or furnishings. Rarely however do studios occur where all scales are considered at the same time, simply because it's difficult to manage and can be confusing for the students involved. However when designing for a circular economy, and especially for the massive wind blades we are focused on, the designer must be aware of all scales and their associated systems. This means that students in this studio must be able to understand their propositions from the large, geopolitical context to the small, the nature of the constituent materials of wind blades.

2. Product over Process. Architecture design studios rely heavily on tutors drawn from practice so there is a cultural tendency for student work to be judged more on the architectural, rather than the learning outcomes; and when that is the case it is the final design product that predominates. Given the scale of this project and the relative early stage thinking around circular design processes, it is unlikely that we will have strong design outcomes after 11 weeks. However the research team recognises that the process of generating, critiquing, prototyping and testing possible solutions will, in and of itself, provide a process template for future work in this area. This presents yet another challenge for the project since because of the dominance of the 'artefact' in design studio culture, design processes (which include the decision making) often lie hidden. These

however are critical to a research project that by its nature must reveal its 'raw data' for examination by later researchers. The challenge here is to capture and make explicit the process.

3. Proposal to Prototype. The proposals developed by QUB students will become inputs to a detailing and prototyping workshop, to be held at Georgia Tech in Atlanta in Fall 2019. The intent is that the handoff between designers and detailers/prototypers leads to a close relationship between ideas and realisations. The obvious difficulty here is that the prototyping students may wish to re-engage in a design process – from the start – rather than to move forward with assessment, redesign as necessary, detailing, and prototyping. Two strategies have been developed to aid in the integration of the two phases: first, both sets of students will complete a sandwich panel composites making workshops – using the same materials and techniques, to build competence and community between the two groups. In addition, the QUB student will be visiting Georgia Tech in Spring 2018 to present their proposals to the prototyping workshop and further build community.

4. Other Voices. Design Studios aim to support diversity but in reality students are rarely exposed to any views or expertise beyond architecture. This generates a value system that is implicit and thus difficult to challenge. It could be argued that without this discourse at the 'coal-face' of design education, students are unprepared for the challenges that lie ahead.

Addressing Pedagogical Issues in the Re-Wind Project

This section outlines the means by which we will address the challenges outlined above.

Scope and Scale: We will develop, in agreement with the research team a clear Visual-based Narrative that explains the need and challenges of recycling blades as they are known at the project's outset. A Masters of Architecture Student has been appointed to carry out this work in advance of the Design studio in order that we can use it to engage and attract students into the design studio. It's anticipated that the research team will also use it to promote the project to wider stakeholders. The clarity of this visual narrative is critical in ensuring that we are all moving in the same direction, yet also allows for creative freedom. As the studio begins we will also begin to Create a Precedent Map. Traditionally Design students look to built precedents for influence, however it is sometimes a shallow gesture and quickly forgotten. Our approach will be to treat this with more rigor, extending the process to collate as many precedents as possible, including process precedents. that are relevant to the project. They will be analysed, categorised and mapped so that we can also spot and understand what is missing from the map. This helps us to build off the expertise and endeavours of others yet also identify potential new areas of investigation.

Product over Process: Documenting the decision making process is critical so we will use two devices. The first is known as Spread Sheet Critique – this involves a formalised and documented

process that records each design proposition (visually and textually); analyses the propositions from a range of perspectives; identifies and lists the next possible steps in development; associated risks, and any outstanding questions. This document will be critical in allowing others within and beyond the project to critically retrace or challenge the process.

Proposal to Prototype: Material understanding is a fundamental component of the Circular Economy. It is critical that designers go beyond the graphical image of a proposal and understand its material nature (embodied energy, workability, life span etc) and impact (environmental, health). In order to bring the students to this level of understanding we intend to trial two techniques. The first is known as a 'Teardown'. This refers to a reverse engineering process, used within the RSA's Circular Economy Design workshop, which offered participants the opportunity to take apart an existing product in order to understand its material complexity. In this instance we intend to deconstruct a small section of a blade. The second technique is a Kit Build where we will design a workshop allowing students to work directly with composite materials, making their own element. The aim is to embed a physical, intimate and tacit material knowledge of composite construction that students can draw on when designing larger scale propositions for wind blades.

Other Voices: For this we will open up the studio to Expert Voices from outside architecture. These formative moments will occur throughout the semester and will allow us to critique the propositions as they are being evolved by the students, from a series of technical, environmental and social perspectives. The Re-Wind project is staffed by a large group of experts with backgrounds in wind power, life cycle assessment, geographic information systems, composite materials, structural engineering, community based practice etc. The role of these experts will be acknowledged and harnessed in the design studio, without overwhelming the students or over-constraining the design process. The integration of experts and their knowledge into the project is described in the next section. (see also fig 2).

Project Structure

The design effort for the overall project is structured into four major phases: (1) a preparation phase, where data and tools are assembled and organized for the design studio; (2) the design studio at QUB which is the focus of this paper; (3) the prototyping workshop at Georgia Tech and (4) the design documentation phase at the end of the two courses.

The QUB studio is also structured in four phases as described below (Figure 2).

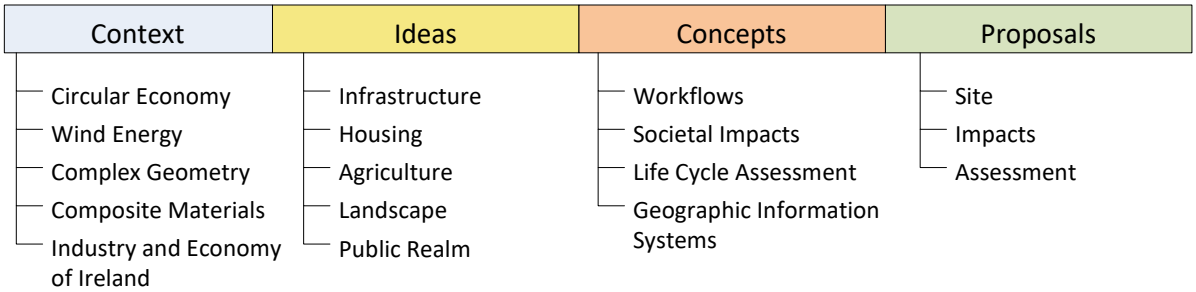

Figure 2: Structure of the Windblade Re-Wind Design Studio at QUB.

1. **Context.** In the first phase of the course, the students are introduced to background knowledge from a wide range of experts – all of whom are members of the Re-Wind research team. In this way, the student designers are equipped to apply this knowledge and "model the experts" in the design process, as described by Christiaans and Venselaar (2005). The problem is uniquely suited to the Island of Ireland, due to: the large installed base of wind power on the island, the environmental ethic of the governments and people of the island, the focus on economic development and preservation of Irish resources.

2. **Ideas.** The second phase of the studio focuses on ideation, that is, the generation of a large number of design propositions in wide range of domains. These ideas will be developed through sketching, coarse 3D modeling, and through discussions with experts, stakeholders, and potential clients for the second-life windblade products. It is anticipated that each student will develop 5 to 10 ideas. At this stage of the design process, the merit of ideas are not assessed – none are too outlandish nor too pedestrian to be considered. The class will develop a pattern book of ideas – and the ideas of other Re-Wind team members (engineers, physical scientists, social scientists) will be interleaved with those generated by the students.

3. **Concepts.** The third phase of the course include the development of workflows (ie design of processes per Ali (2017)) and the formulation of assessment strategies to quickly assess the ideas generated in phase 2. Promising ideas will be identified and alloyed with informal workflows that depict the windblades as they transition from tower through remanufacturing to re-use site. Assessment will include metrics that assess the percentage of material reused, the carbon sequestration by mass and duration, and the potential societal impacts (both positive and negative) of the idea. We anticipate that each student will generate three concepts, each taken from either one of their own ideas – or from the ideas of other students or project team members.

4. **Proposals**. Finally, each student will develop one proposal that embodies the traditional deliverables for an architectural project, including the selection of specific windblades from the Island of Ireland, at a specific site. The re-use application will be fully documented at a specific (likely different) site, and with fully documented architectural and process drawings. The proposals will include a refined process model documenting the geographical and logistical operations necessary to transform the windblades from active use on a tower to the repurpose application

on the Island of Ireland. The proposals should have sufficient detail for the follow-on prototyping workshop at Georgia Tech as well as for the team of ecological and social scientists and structural engineers whose work will follow the design studio.

SIGNIFICANCE AND CONCLUSION

This Paper was written as we were planning the Design studio (6months in advance) so it has helped to frame and provide a wider context and place for reflection on the nature of the challenge than would normally be the case. This means that there are, at the point of writing, no research 'findings' for the paper to report. However as we plan how best to conjoin a Design studio and a research project we have started to consider that there is potential for the project to trigger other outcomes beyond those outputs we initially anticipated. We believe that the visual 2 and 3-D outputs of the design studio can be used to raise greater public awareness around windblades and circular economy issues and as such we hope to curate a series of public exhibitions/ presentations. The design process and project as a whole will identify those aspects of current blade design and material composition that present the greatest difficulty when repurposing, and we hope that information may potentially influence the design of future blades. We also understand that whilst the scale of the problem addressed by the research project is vast – any solutions will create commercial opportunities of a relative scale and significance. This will be a new area of industry that needs a new generation of professionals. So finally, by aligning a research project to a design studio we believe it has the potential not only to demonstrate the power of design thinking in these complex, large scale situations but will offer a new form of design studio from which a generation of 'circularity' designers with emerge.

ACKNOWLEDGEMENTS

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TRANSITION ENGINEERING URBAN CANYONS - ROGER STEVENS COOLING POND CASE STUDY LEEDS, UK

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Keywords: Transition Engineering; Urban Heat Island Mitigation; Blue-green infrastructure; Nature-based solutions

Abstract

Our research project focuses on assessing microclimates associated with water features and green infrastructure set among the "Brutalist" concrete canyons developed in late 20th century, and Transition Engineering (identifying pathways) to exploit storm water to mitigate the combined impact of urban heat islands and global warming as far as the end of the 21st century. As a case study we are monitoring the environs circa the Roger Stevens Building (1970) which Heritage England listed at Grade II as a fitting centrepiece to the group of additional buildings on the south of older Red Brick University of Leeds which inspired the "plate glass university" building boom throughout the UK during the 1970. The precinct includes a "Cooling Pond" identified by the Ordinance Survey, which since 1983 reflects upon a flying bronze figure removed from the Midland Bank in London, "keeping a watchful eye out for impromptu swimmers". There is no evidence that the Cooling Pond was ever connected to any mechanical building services by pumps or pipework. We are investigating how the role of this water feature have been evolving over almost time and what role could potentially play today in line with a more contemporary idea of blue/green infrastructure. The pond is currently undergoing redevelopment to allow the previously chlorinated sterile water feature to become a thriving bluegreen ecosystem, as a collaborative living lab involving Estates Services, Sustainability Service, Water@Leeds, School of Geography, School of Biological Sciences and School of Civil Engineering. Within this project we aim at assessing ambient air temperature surrounding the Roger Stevens Building before and after the redevelopment of the Cooling Pond.*

INTRODUCTION

Interdisciplinary transition innovation, management and engineering are the staged components of the 7-step methodology (Krumdieck 2013) for Transition Engineering to overcome wicked problems. The concept of "wicked problems" (Rittel & Webber 1973) has been alluded to in countless examples of land and resource management. Examples of such problems include urban land management (McPhearson et al. 2016), policymaking (Head 2008), climate change (Grundmann 2016), and the conservation of biological diversity (Redford et al. 2013). The specific criteria that apply to true wicked problems have been outlined elsewhere, but, in summary, these are challenges that are highly complex, have many interacting

stakeholders, and lack an obvious solution. Wicked problems compound one another when they come into contact. In this paper we outline some wicked problems that exist at the shared borders of different fields of work. Case in point, we are challenged by wicked problems, borne out of mutually-exclusive priorities from different fields, converging within a small pool in a city in the north of the United Kingdom (Figure 1).

Figure 1. Outlook from Waterview Café across the Cooling Pond towards screened temperature sensor on the corner of the Food Science Building.

The Roger Stevens Pond has been identified for development and improvement by Leeds University Estates Services due to ongoing maintenance issues associated with its pumps and fountains. The Pond needs to be drained every time the pumps and fountains need maintenance and this can happen several times a year. When the system isn't working effectively there is commonly a build-up of algae which is unsightly and potentially hazardous to wildlife. A project was therefore set up to identify a more sustainable management method that replaces the need for pumping with a more natural approach. By introducing planting to the pond both the amenity and biodiversity value of the pond will be significantly increased whilst reducing the time and financial costs of maintenance.

The project was identified as an opportunity to take a living lab approach to the development and management of the area. The Leeds Living Lab brings together students, academic and professional staff to co-create innovative and transformational solutions to real-world sustainability challenges, using the University as a testbed. It is interdisciplinary and drives continual, sustainable improvement by tackling global challenges at the local scale. Academics from the Faculties of Biological Sciences, Engineering, and Environment were brought together in a project team with colleagues from Estates Services and the Sustainability Service to co-create an innovative space for research-led teaching. This initially brought the benefit of leading academic expertise into the consultation process and helped the University to identify the most effective solution and approach, such as the types of planting, the species selection, and conclusions on current options for water sources. It is now allowing Schools across the University to identify ways in which they can utilise the pond for teaching assessed student projects. Plans include installation of sensors for environmental monitoring, an online data dashboard, species selection that provides amenity value, biodiversity enhancement and academic interest, and safety and access to allow all ages to utilise the pond for field learning.

The project brings with it an opportunity to better understand the current micro climate of the Pond and its surrounding area, and to monitor how this might change with the introduction of planting. Development plans for adjacent and connecting areas may allow for further water and greenspace landscaping so Estates Services will gain from improved knowledge and awareness of the potential benefits to climate control in terms of buildings efficiency and staff wellbeing.

The University is committed to immediate changes this summer (2018), including removal of the fountains and the installation of a floating 'Biomatrix' to improve natural management of water quality, and to enhance biodiversity and amenity value. The Leeds Living Lab project delivery team are keen to continue to support research-led teaching on campus, and will be guided by academic experts regarding planting regimes as well as design features that support access to both the pond itself, and to monitoring data. The idea is to produce a learning loop to attempt incremental improvement of the pond while maintaining a collaborative safe operating environment for research, teaching, and urban biodiversity. Given the significance opportunity, the micro-climate urban heat island effects will continue to be monitored this summer to observe any detectable impact. So the present paper presents preliminary results of a Transition Engineering analysis of key system dynamics. The authors of this paper came together in discussion over how to implement a programme of enhancement of a fifty-year-old water feature (30m x 30m, depth ca. 0.5m) on the campus of the University of Leeds in the UK shown in Figure 1. A search of archival plans has confirmed that there never was any abstraction of cooling water for any sort of mechanical building services, but it still bears the place-name "Cooling Pond" on the Ordinance Survey presented by Historic England in listing the surrounding buildings. So, it is surmised that the Cooling Pond might have been conceived in the 1960s by Chamberlin, Powell and Bon Architects to mitigate the expected urban heat island effects (Bornstein 1968) of their development plans for the South Campus of the University of Leeds.

The Cooling Pond is interesting from a number of perspectives. First, it has small fountains and lights for aesthetic appeal, although these are in need of replacement. Second, the concrete lining of the pool provides no habitat for the establishment of plants or animals and so the only natural components of the pond are a dense algal community and a pair of mallard ducks that routinely nest in a duck house on the edge of the pool. Those mallards produce 5-7 chicks each year before leaving the site, and are extremely popular with the local students. Third, the Cooling Pond is part of a larger Grade 2* heritage listed building, the Roger Stevens Lecture Theatre Block, which was completed in 1970 – representing a prime example of the brutalist architectural movement that swept across the UK in the following decade. Fourth, there are many ongoing problems with the pond, including the need to completely drain the water several times over the spring and summer period to remove the algal and clean the concrete lining. Because of leaks into laboratories below, the southeast arm of the pond was decommissioned before heritage listing, and now is entirely contained by membrane over concrete slab-on-earth construction. Collaboration between academic and operational teams will now research global challenges and deliver sustainable solutions, using the Cooling Pond as a testbed as long at the architectural container is untouched. Our focal water body, the mirror pool itself generates a cultural ecosystem services associated with the built heritage of the structure and provides evaporative cooling to reduce temperatures in a densely-

constructed city. The question is: can we retain those ecosystem services while enhancing the biodiversity value of the pool? The evidence suggests that biodiversity of standing urban waters is relatively robust (at larger scales) to the impacts of urbanisation, and that biodiversity can co-exist with ecosystem services. The various circumstances of our case study combine to illustrate two related wicked problems.

The Urban-Ecological Problem

Competition for land between nature and human use has dominated the fields of environmental and biological sciences over the past 50 years. Human impacts are the predominant cause of biodiversity decline (Tilman et al. 2017), while biodiversity itself underpins a wide range of processes and services that are essential to the healthy functioning of human societies (Duncan et al. 2015). The relationship between ecosystem services and biodiversity is not linear in all cases (if any). Links between health and biodiversity suggest that a greater number of species is associated with increased health outcomes (Fuller et al. 2007; Hanski et al. 2012), but the same is not true of the relationships between biodiversity and pollination (Kleijn et al. 2015) or carbon sequestration (Sullivan et al. 2017). The challenge, therefore, has been to develop an approach to land management within which natural and human systems coexist in a mutualistic manner. Nowhere is that more challenging than in urban landscapes, due to the intensive use of space for human purposes (Eigenbrod et al. 2011). Studies of the impacts of cities on biodiversity have concluded that urban ecosystems usually act to reduce biodiversity and homogenize biological communities (McKinney 2002; McKinney 2006), as found plants and insects (McKinney 2008). However, fresh waters are a notable exception, where pond biodiversity tends not to show variation in relation to larger scale land use patterns unaffected by surrounding urban landscapes (Hill et al. 2016). This opens up the possibility for urban water sources that can provide their ecosystem services and still serve an important role in wider ecological function. Urban lakes and rivers have been studied from a variety of perspectives and are known to produce health benefits through mitigation of the urban heat island and generation of natural noise (Völker & Kistemann 2011), provide water for drinking and washing (Nagendra & Ostrom 2014), and generate cultural ecosystem services (Kumar 2017). These ecosystem services can co-exist with biodiversity (Hassall & Anderson 2015), although the evidence for such “win-win” scenarios is scarce. The wicked problem from the ecologist’s perspective is how to enhance nature in urban spaces without compromising the function of cities for human purposes.

Engineering-Heritage Problem

Contemporary cities integrate historical urban patterns with new stratifications that in some cases evolve organically, comprising a large diversity of building forms and functions. When local society and culture recognise themselves in specific buildings, which are considered of value, then heritage schemes are set in place to protect them. The schemes also allow promoting the value of the built heritage to local economies (Richards 1996). There is an inherent challenge in updating built heritage for contemporary use without compromising the values of that heritage. In most of the cases, those buildings were built when there was less attention to energy efficiency. Moreover the increasing global temperature is stressing the current built environment. Many recent studies have attempt to develop strategies for the

energy retrofitting of heritage buildings while still maintaining the heritage values (Martínez-Molina et al. 2016). However, there is not a one fit-all solution. Therefore, how to reduce the energy demand of buildings protected by heritage restrictions is still an open question. (Mosley 2013).

Path-breaking out of business-as-usual traps

To break out from wicked problems, objective metrics need be established in accordance with the initial steps of the Transition Engineering approach (Krumdieck 2013), following the discipline of Safety Engineering. The process begins by auditing records, monitoring and investigation to understand where sustainability problems arise. This background enables stakeholders to see if established trends will result in an un-sustainable operating environment if business-as-usual continues without timely proactive remedial changes. These metrics are long term key performance indicators of resource availability - such as energy, water, and air quality.

RESEARCH METHODS

In the present paper we describe how we are in the process of employing first three steps for stakeholders to understand the system dynamics of infrastructure such as the pond. The present case study focuses on an isolated water feature that has been maintained with potable water mains, and is not connected by natural water courses. An integrating surrogate for water condition has been assessed by the biodiversity of the pond. It is understood that air quality by way of nitrous oxides in the urban canyons of Leeds is being monitored by others, but in the present circumstance we have found that we can employ urban heat island intensity (UHII) in a hourly comparing of the urban ambient temperature with airport observations from the open lands of the greenbelt, similar to the approach of Levermore and Parkinson (2017). This would have been difficult since the Weather Centre in the Leeds Town Hall closed in 2003, but fortunately the University established a new weather station one km northwest of the City centre, on the roof of the Building that houses the Schools of Maths, and Earth and Environment. The altitude difference between the two meteorological stations was accounted for by assuming the wet adiabatic lapse rate of 7°C per km. Consequently, we observed urban heat island intensity during spring 2018. Using the new on-campus weather station we deployed screened temperature sensors to measure the micro-climatic heat island intensity (µHII) variations between four outdoor areas on the campus of the University of Leeds as illustrated in Figure 3.

Figure 2. Precinct surrounding Waterview Café (upper pane), with four radiation-screened temperature sensors deployed to monitor micro-climate variations (lower panes). In the map please find Chancellor's Court (light green); the Cooling Pond (blue); Cark Park south of the EC Stoner Building (grey); and the Edge on Willow Terrace Road

Both the screen temperature in the Chancellor's Court (lower left of Figure 2) and pond-side (second from the left in Figure 2) were compared with the roof level campus weather station as representatives of green and blue infrastructure.

RESULTS

The ambient temperature of Leeds would be expected to be warmer than the airport moorlands that are located at a higher altitude, yet the urban heat island has increased by an incrementally greater quantum difference. Figure 3 has removed altitude effects, to present the heat island intensity attributable to anthropogenic effect of the urban system – where median (50%) UHII was generally observed to be more than +2°C – except during more settled dry weather in May 2018 the daytime UHII increased to +2°C and dipped at night. We will continue to monitor the hourly profiles of UHII as we progress into the summer months, and use this local baseline to measure the micro heat island intensity (µHII) of various urban canyons surrounding our case study.

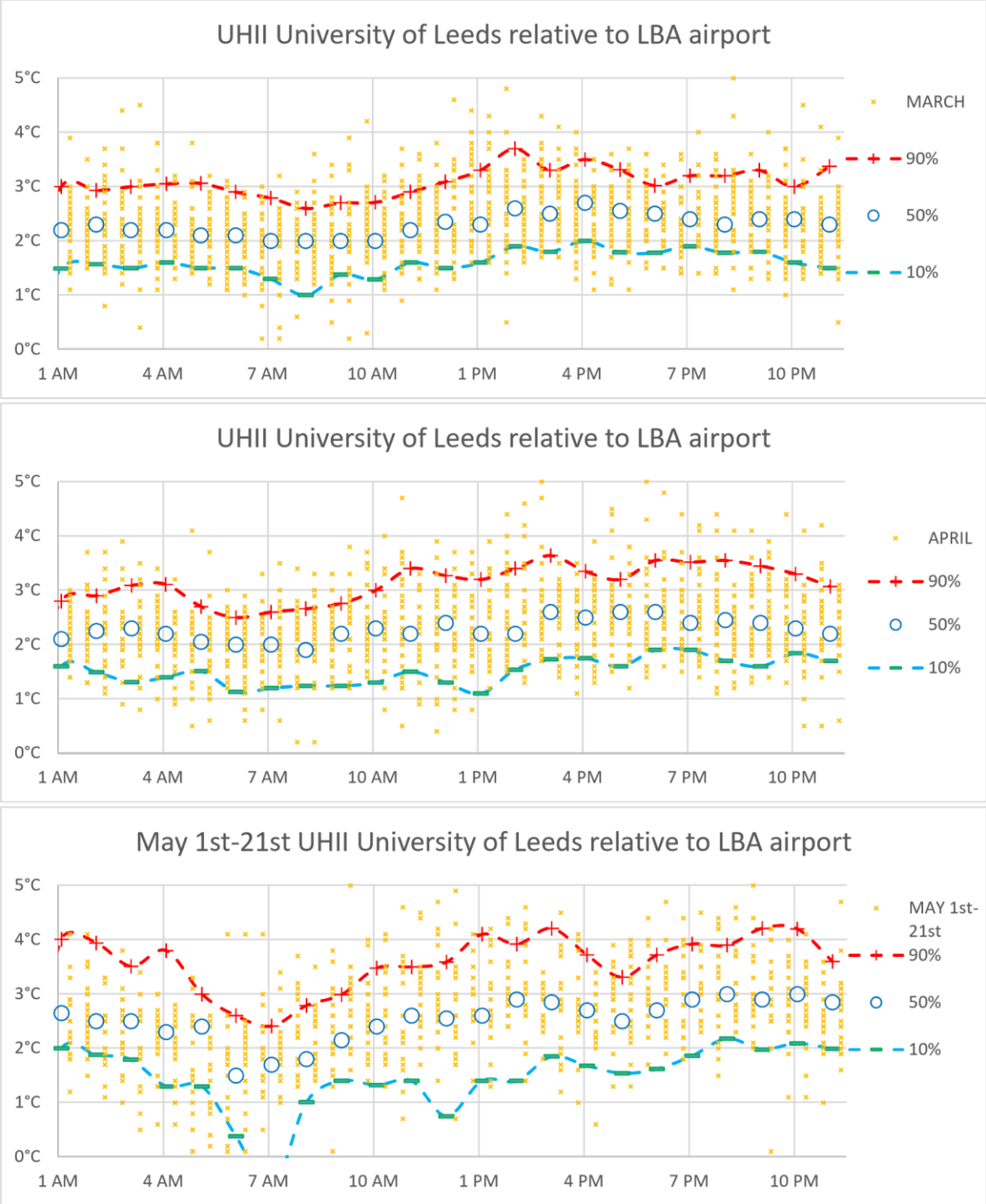
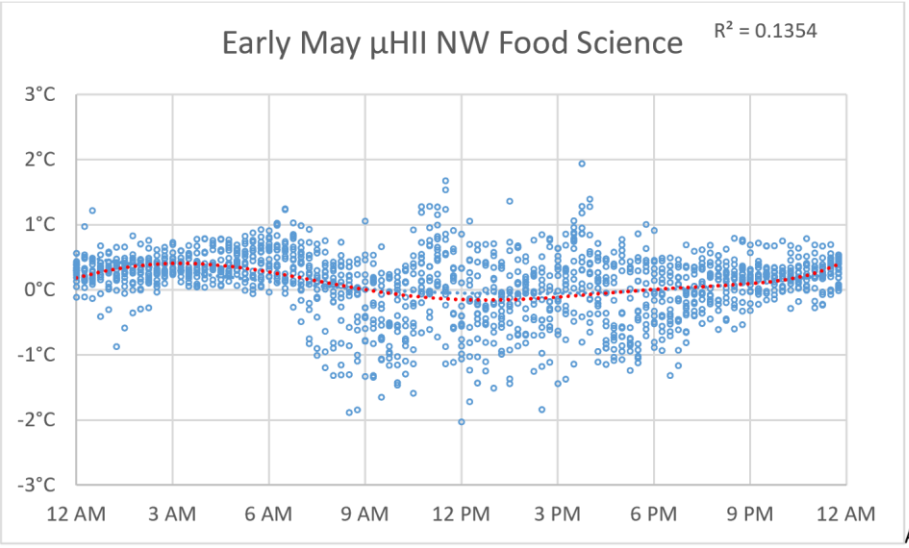


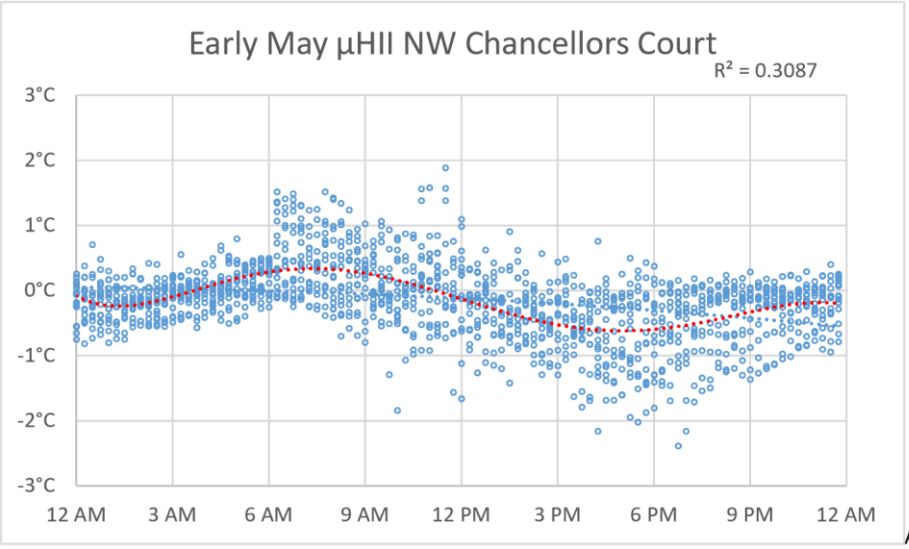
Figure 3: Urban heat island intensity of the University of Leeds weather station relative to Leeds-Bradford International Airport (LBA) Upper pane – March 2018; Centre pane – April 2018; Lower pane – May 2018 (until Monday 21st May)

Micro-climate heat island intensities (µHII) are plotted in Figure 4 for the month of May 2018, with sixth-order polynomial regression R^2 showing 30% and 13% of the variability is associated with the time of day. Chancellor's Court micro urban heat island intensity (µHII) drops during the afternoon as sun is shaded by the Staff Centre Building. The pondside, NW corner of the

School of Food Science Building remains exposed to afternoon sun, directly and reflected by the pond, and so has a fractionally elevated µHII.



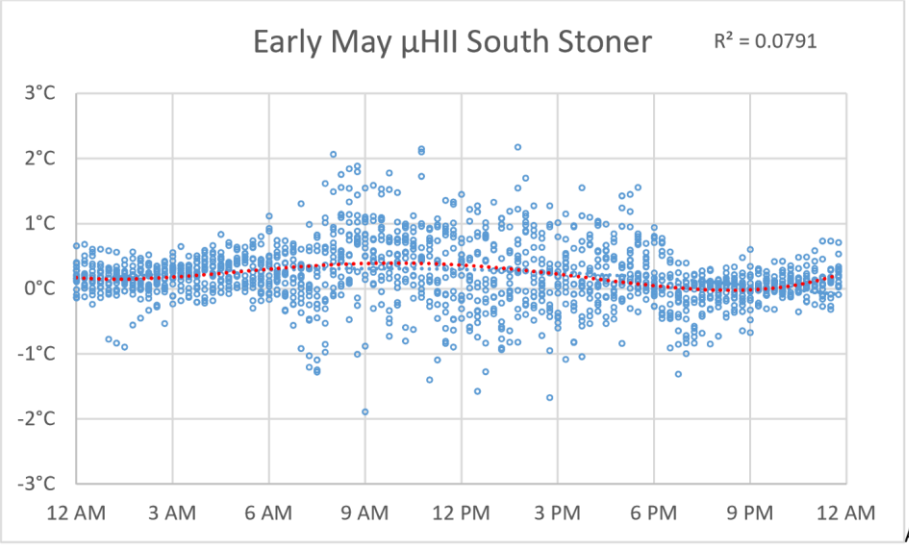
Average +0.2°C ±0.9°σ



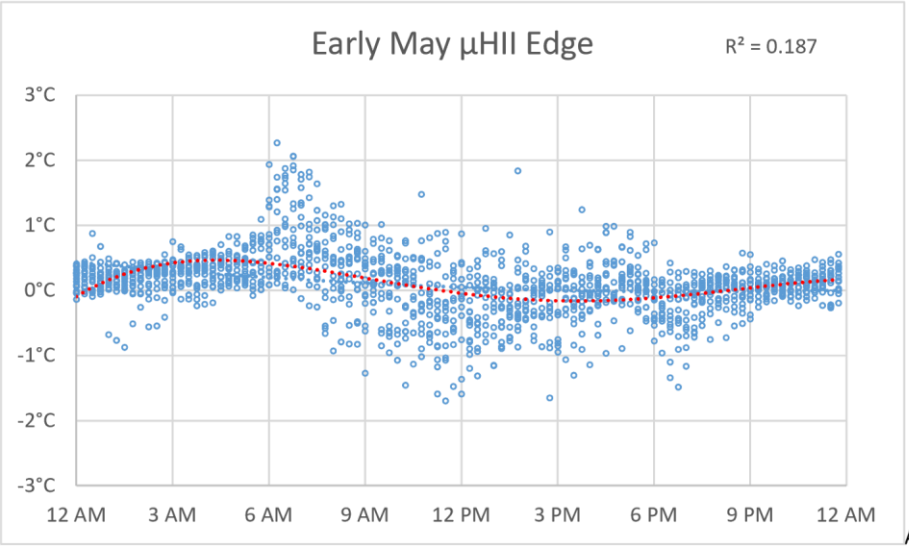
Average 0.0°C ±0.5°σ

Figure 4: Blue and Green micro-climate heat island intensities (µHII relative to the University of Leeds weather station) Upper pane – NW of School of Food Science, NE of the Cooling Pond – example of blue infrastructure Lower pane – NW of Chancellor's Court,
East of Staff Centre – example of green infrastructure

Similarly, two locations further from the pond and gardens are compared with the roof level campus weather station in Figure 5, with R^2 showing only 8% and 18% of the variability associated with time of day at the parking area south of the Stoner Building and at The Edge on Willow Terrace Street. The Edge appears to benefit from afternoon shading, but not as well as the Chancellor's Court. Micro-climate heat island intensity is generally positive on the south of Stoner Building, and only a small hedge of vegetation is present to mitigate.



Average +0.1°C ±0.9°σ



Average +0.1°C ±0.9°σ

Figure 5: Micro-climate heat island intensities (µHII) relative to University of Leeds weather station Upper pane – Finsbury Road, South of EC Stoner Building – gravelled parking 100 m east of Cooling Pond Lower pane –Willow Terrace Street, NE of The Edge Building – service road below the Cooling Pond

In both figures 4 and 5 the swarm of data is much tighter at night, and scatters markedly during daylight – indicating that thermal radiation is differentially impacting microclimates even though sensors are performing very well to eliminate short wave solar radiation.

CONCLUSIONS

We have not completed the Transition Engineering process of resolving competing wicked problems, looking through two lenses: Urban–ecology, and engineering–heritage. What has been achieved is that we have measured the urban heat island intensity (UHII) of our campus that is located 1 km from Leeds Town Hall, and within one precinct we have investigated variations in the micro-climatic heat island intensity (µHII), finding that green infrastructure that is shaded in the afternoon is cooler than concrete-lined blue infrastructure.

On-going monitoring of the Cooling Pond could help resolve the ongoing trajectory of enhancement efforts. Our consensus is that it is justified to install water-column DO/salinity/temperature logger, and auditing of the occasional refilling events. A chlorophyll logger would be nice-to-have, but is not expected to be funded in the foreseeable future. The School of Biology is equipped to provide regular sampling with specimen storage and cell count estimation using spectrophotometry, but recommends that a "Sustainability Student Champion" be elected among students to provide an annual report card on pond health if a part-time role could be funded by the Sustainability Service as a part of the Leeds Living Lab.

Now there appears to be some consensus on immediate interventions that are recommended to maintain the Cooling Pond in a safe operating environment, as follows.

1. Engineering-Heritage: A sustainable solution to the algal bloom problem is the addition of a more coherent ecosystem, based around macrophytes to oxygenate the water and invertebrates to graze the algae. This would vastly reduce, if not eliminate, the cost of cleaning. However, the addition of such an ecosystem would need to be done in keeping with the heritage listing of the building, presenting a key ecological challenge.
2. Urban-Ecology: The University of Leeds campus lacks freshwater habitats for mallard ducks are likely contributing to the problem, through the excretion of nitrogen into the water which then provides nutrients for the algae. However, those mallards cannot be removed without careful management of the perceptions of the local site users.

The resolution of wicked problems of ensuring the sustainability of the Roger Stevens Cooling Pond may depend on a more complete historical reconstruction of the past halfcentury, complemented with the development of a Living Laboratory Dashboard of real time monitoring such as has been availed with the University of Leeds Weather Station, so that stakeholders are able to project trends into the future. The next step is to consider if incremental changes will ensure that the Cooling Pond can be maintained in a safe operating environment. Transition Engineering suggests that all concerned be prepared for a substantial change in direction over the next half century.

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Sustainability Education

CHANGING MEDICAL EDUCATION CURRICULUM: CHALLENGES, PREPARATION AND IMPLEMENTATION OF CHANGE

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Abstract

Universities are well known for their professional bureaucratic nature, in particular resistance to change. This can be described as behavioural apathy, which is the tendency to preserve the existing organisational structure, even when it is clearly inefficient and unsuited to official goals. This is widespread within universities worldwide, in the shape of a combination of organising practices which are historically located and capriciously resistant and resilient. Behavioral apathy can affect the ability of universities to successfully change curriculum, creating resistance to any alteration of existing practices. Even if a proposed curriculum change is supported by the majority of stakeholders, there are factors that play a role in how well the change is received, implemented and maintained. Those factors are resistance against change, internal communication on change, empowerment and involvement and organisational culture. Bringing change to education curriculum requires adequate preparation and ground settings in which change can be implemented and accepted. There are a number of issues for change leaders to address and prepare before deciding to implement a curriculum change in medical education. This case study will take a closer look at the potential challenges faced by the MD 2020 curriculum at the University of Sydney may face.

INTRODUCTION

Changes in education curriculums and in modes of teaching and learning are common in higher education institutions (HEI). Change therefore becomes a regular and familiar component and/or process in higher education management. However, many people in academia find that change, particularly in curriculum reform, is a challenge. This challenge becomes greater when change becomes more dynamic and complex in HEIs. Today's higher education has the tendency to move towards optimising integration between multi-disciplinary learning facilities within and outside the institution to gain worldwide recognition. The complexity of change requires rigorous attention from top management, change management specialists and/or institutional leaders to identify and analyse the key drivers and effective approaches to bringing change in curriculums. Understanding whether an institution is ready to accept change can be a complex process, especially if the institutional culture is nurtured or dynamic, the requirements for change are identified, the approaches of change are defined, goals are set

and strategies are formulated. Even once universities have established an environment for change and embraced the curriculum change proposal, it is still challenging to reform the curriculum because offerings of higher education follow a complex systems approach, often influenced by technological innovation, social needs, university–industry alliances, the demand–supply gap of producing graduates and global trends of learning and recognition. This study is a critical example of welcoming and initiating a curriculum change at the tertiary level in medical education provided by the Sydney Medical School, Australia. The practical view of the objectives of this change are to offer Sydney Medical School students assistance in preparing them for entry to the MD program; to prepare students for clinical and research practice; to offer students opportunities to develop Personalised Pathways through the program to foster expertise in the area of their choice; to tie in with industry needs (such as hospital service requirements); to adapt sustainability and competitiveness in providing medical teaching and learning; and to facilitate a dynamic change management mechanism in learning to accept the influence of virtual reality use as well as understand e-health technology applications and online automated moderating assistants in learning and online platforms in order to improve communication between medical practitioners and medical students.

LITERATURE REVIEW - OVERVIEW OF CHANGE MANAGEMENT PRACTICES IN HIGHER EDUCATION

Researchers have identified that having links between government policy and leadership skills (such as motivation, personality, knowledge, experience and communication) can create one of two paths: either effective or ineffective management of higher education institutions (Ngirwa et al., 2014; Mumford et al., 2000). If the leaders do not consider academic needs (such as academic freedom, autonomy, respect and collegiality) and management processes are participatory, exercising power and directive leadership, then negative perceptions among people at the university, for example, academics and support staff, may be created and they will not welcome change. However, the use of staff participation, negotiation and positive leadership to develop favourable policies that support fulfilling the needs of academic staff can lead to acceptance of change initiatives in higher education institutions (Ngirwa et al., 2014).

Verhulst and Lambrechts (2015) identify several human factors as barriers for bringing change in higher education. These can be grouped into three areas. The first area involves lacks in awareness (including a lack of interest and involvement), support, professionalism, policy-making and recognition. The second area is unsupported structure of higher education, including the conservative disciplinary structure of higher education institutions, inefficient communication, resistance to change, overcrowded curriculum and focus on content-based learning. The third area is the need for more resources, including a lack of funding, heavy work pressure and lack of time, lack of access to information, lack of consistent legislation and lack of physical place.

A review of managing change in higher education institutions (HEI) in a global context suggests that curriculum change is influenced by internal (top management at universities) and external (government, education ministries) key players. In French universities, the government plays a key role in changing curriculums. The Ministry of Higher Education strengthens universities' ability to bring and manage change in curriculum and design program courses. The involvement of academics in curriculum change within French universities has been increased in the recent past (Louvel, 2013). In the United Kingdom (UK), the Quality Assurance Agency (QAA) is responsible for protecting standards across higher education institutions in the UK. However, QAA has been consistently identified as weak in comparison to the higher education standards maintained by Australia and Hong Kong (Medland, 2016). The honours degree offered by UK universities is a highly valued qualification but the degree classification system does not meet the purpose of and cannot explain the skills or the range of knowledge, experience and attributes of today's graduates. Medland (2016), therefore, argues there is a need to review and change the curriculum. There are range of internal and external factors that derive this need for change (Medland, 2016).

Implementation of curriculum reform is a challenge because the objectives of change can be undermined by poor implementation (Gornitzka et al., 2005). Important changes come through political and governance support. Often, the implementation phase becomes the last occasion to burden the change not only by those who are opposed to change but also by those who did not participate in designing the change and were not part of the decision-making process. However, in the Netherlands's higher education system, changes are stimulated by relevant external and internal governance.

Towards Leading Curriculum Change

Change can bring many benefits to universities, such as the ability to offer more online courses, which allows people who may not normally be able to access higher education and universities to increase enrolments without having to build more physical infrastructure (Norton, A., & Cakitaki, 2016). Thus, educational leaders need to think strategically about the future of learning communities and greater purposes of activities or initiatives that need to be put in place. The application of critical leadership skills is necessary to enhance the success of curriculum initiatives in higher education institutions (Nousiainen et al., 2017; Bikmoradi, 2009; Bland et al., 2000). It is also vital to let the people affected by change to know the rationale and process of change. Individual commitments to educational beliefs and values help change to happen. In a higher education environment, change management leaders need to be aware of the skills and interests of academics (Keesing-Styles et al., 2014) in order to able to activate participants to hold the momentum of change (Bland et al., 2000). Additionally, participants need to be encouraged to engage in decision-making and their values need to be incorporated in the change process (Keesing-Styles et al., 2014). In addition to the involvement of academics in curriculum change initiatives, it is critical to identify the professional development needs of

the staff who will be involved in change and to provide relevant training and activities organised at a place close to the actual change initiative (Nousiainen et al., 2017; Bok et al., 2013; Keesing-Styles et al., 2014; Barth & Rieckmann, 2012; Dath et al., 2010; Ruiz et al., 2006). This helps participants to attain contextual knowledge with a sense of change that may enhance their positive engagement in the change process. A practice assessment is required involving staff, students and other key players to ascertain whether the statements presented in change documentation match with practice and whether the process in the project phase is ready to move forward. In leading curriculum change, academic advisors from the learning and teaching units work with academic teams to map the current practice against the desirable features of the new curriculum. Academic advisors are then offered professional development that addresses the curriculum's gaps and needs and facilitates additional resources with the platform to engage with institutional communities of practice to discuss the initial curriculum mapping (Keesing-Styles et al., 2014).

Factors Affecting Leaders in Change Management

The change management literature shows that the most effective factor for being successful in curriculum change is appropriate leadership that is stable, confident, flexible and able to motivate others to positively maintain the change momentum (Nousiainen et al., 2017; Ngirwa et al., 2014; Mumford et al., 2000; Bland et al., 2000). The leaders of change need to communicate change mechanisms clearly to stakeholders and promote a shared vision for curriculum change. The leaders need to ensure that their efforts are well connected to the mission and the goals of the faculty as well as the institution. Resource management plays a large role in the success of a change project. The leaders thus need to ensure that there are adequate resources for change initiation and that the funding continues as change progresses (Nousiainen et al., 2017; Bland et al., 2000).

Interplay Between People, Structure, Dialogue, Relationships and Networks

Social learning and social connections are prerequisites in change management in sustainable higher education (Barth & Rieckmann, 2012). Organisational social networks play a significant role in managing change. Diverse types of network structure are relevant to the success of change initiatives (Hoover & Harder, 2015). Structures are seen as a vehicle for achieving change though individual and group processes, facilitating with platforms for individuals to participate in change programs including change planning, the coordination of activities, professional development and decision-making (Hoover & Harder, 2015). Social networks can lead to collaboration and enhance dialogue to develop new relationships. These relationships can build networks and the networks can further enhance relationships. Individual or collective dialogue helps to develop and expand the change initiatives amongst the member of the organisational networks and viceversa. Overall, the interplay between people, structure,

dialogue (communication), relationships and the networks can support and undermine the success of a change project in higher education institutions (Hoover & Harder, 2015).

Role of Academic Middle Managers in Curriculum Change

The role of academic middle managers in higher education and curriculum change has been classified as a complex representation of four dominant scopes: representing core organisational values, being a conservative and self-directed agent of control, being a reinvented managerialist corporate bureaucrat, and being a repository of organisational wisdom (Rudhumbu, 2015). Higher education literature shows that academic middle managers are key players in higher education institutions, particularly in curriculum change projects. They have a high degree of responsibility due to their strategic presence in organisational structures, enabling them to be well informed about the everyday activities and strategies of the instruction. Academic middle managers then become focal points or central actors in institution-wide communication networks connecting vertically to both top management and the operational core at the bottom level. These middle managers also become horizontal integrators, enabling the coordination and dissemination of information, resources and knowledge across the institution and all departments. Academic middle managers are, thus, critical personnel in the planning, implementation and overall management of curriculum change in higher education (Rudhumbu, 2015; Kallenberg, 2007).

Critical Factors Affecting Strategic Change Processes in Education Projects

When managing institutional change, resources play a considerable role in the success of the change. Insufficient resources are one of the factors that cause difficulties in managing change in higher education institutions. Academic staff resist change due to heavy workloads, changing work settings, a scarcity of resources and job-related stress (Mumford et al., 2000). Student enrolment is another issue that arises during change and it needs to be carefully addressed. Increasing student enrolment without a situational adjustment or without adequate resources (e.g. the number of academic staff needed) has become a widespread practice in higher education institutions (Mumford et al., 2000). If these issues are not actualised before bringing in a curriculum change, the change may be negatively affected. From a project management view, the result could be a change disaster; from a strategic management view, it could be a mission-less direction; from integration and innovation points of view, it could be an unconnected move; and from a development point of view, it could be overlooking 360-degree stakeholder inputs or citizen engagement within the HEIs.

In order to understand institutional change management, researchers have studied the factors that influence change processes. A factor can be a supporter or a barrier to the change process. Success factors and barriers are strongly correlated and complex to model. A factor can support

a change process in a certain situation, while the same factor can hinder another change process in different conditions (Verhulst & Lambrechts, 2015). It is therefore more accurate to use the terms critical factors or key drivers rather than labelling individual factors as success factors or barriers. Verhulst (2012) reviewed organisational change management literature and identified sixty influencing factors, many of which were people related. These are often described as human factors or the soft side (e.g. soft skills, people skills). In addition to this, Verhulst and Lambrechts (2015) identified four interrelated clusters of human factors that influence change processes in higher education: resistance against change, internal communication on change, empowerment and improvement, and organisational culture.

Approaches and Directions for Change

Academic staff are unlikely to change their current practices of curriculum and course delivery unless they are communicated with effectively and convinced about the need for change and the potential outcomes of the change initiatives (Medland, 2016). Change in a curriculum requires the investment of resources, which is not a risk-free activity as staff often feel anxiety when discussing the change and development of courses in higher education (Medland, 2016; Boud & Falchikov, 2007). There is little evidence of institution-wide approaches to change (Boud & Falchikov, 2007) and, to successfully achieve change, an institution must first establish its starting point; i.e., understand its current practices (Medland, 2016).

In a curriculum change project, the role of leadership and the processes of change reveal the need for both bottom-up and top-down directions to address the comprehensive context of the change. Using only a bottom-up approach of leadership engagement would systematically ignore the institution-wide structure and run into significant problems, while a solely top-down alignment of leadership would typically run into problems with buy-in (Kezar et al., 2015; Kezar, 2001). A successful implementation of change requires proper alignment with other courses in the curriculum and the support of the administrative leadership to offer rewards and incentives as well as the resources for professional development. With a bottom-up approach, integrating change from the top is difficult to establish and the project often faces barriers to moving forward (Kezar et al., 2015).

Bringing Change to the Medical Education Curriculum

Bringing change to education curriculum requires adequate preparation and ground settings in which change can be implemented and accepted. There are a number of issues for change leaders to address and prepare before deciding to implement a curriculum change in medical education (Nousiainen et al., 2017). The key preparation of change includes organising structural changes that facilitate the delivery of new curriculum and the methods of assessment; updating the mode of teaching and evaluation; and fostering an adaptive culture so that changes to curriculum gain acceptance.

There are important considerations that will support positive change in medical curriculum. These include educational continuity at all levels of medical education, the use of information technology-supported teaching delivery (Nousiainen et al., 2017; Ruiz et al. 2006), the flexible use of time as a resource for competency-based learning, the alignment of change with faculty development (Nousiainen et al., 2017; Bok et al., 2013; Dath et al., 2010; Ruiz et al. 2006), ensuring there is a learning environment that is supportive and where learners' rights and responsibilities are well balanced, costing the change to make sure there are adequate resources for the change implementation, and appropriate and effective leadership for a successful implementation of change (Nousiainen et al., 2017; Bland et al., 2000; Bikmoradi, 2009). However, not all changes bring positive values to the institutions. Bikmoradi (2009) finds that the integration of medical education and health services in medical universities could lead to complex changes and overloaded tasks and responsibilities for both faculty and academic leaders. In the case of Iranian medical universities, evidence suggests that a large number of academic managers are not ready to lead (Rudhumbu, 2015; Bikmoradi, 2009).

METHODS USED IN THE STUDY

There is widespread conviction that case studies are useful when studying change (Johnson-Cramer, Cross, & Yan, 2003; Muratbekova-Touron, 2005; Van de Ven & Poole, 2005). Case studies have been used as a research method in disciplines such as sociology and business, analysing both individuals and groups (Yin, 2009). This type of research has been used to better understand complex social phenomena. Change in an organisation interacts strongly with the transformation processes that affect the sectors and environments with which it has important well-consolidated or potential links. This paper focuses on the University of Sydney's MD curriculum review, which took place between 2017 and 2018. As stated earlier, it can be complex to determine whether an institution is ready to accept change. Therefore, a change sizing survey was conducted at the University of Sydney Medical School to identify the requirements for change, to define the approaches for the required change, and to set goals and strategies to achieve the necessary changes. The change sizing and readiness survey was run separately for professional and clinical school staff and for the academic and senior staff (i.e. heads of schools, block chairs and relevant senior instructors), as we believed that the two groups of staff would most likely have different concerns and needs.

This change sizing and readiness survey is based on the awareness, desire, knowledge, ability and reinforcement (ADKAR) model (shown in Figure 1). The survey participants were asked 17 multiple-choice questions and three open-ended questions. For the multiple-choice questions, participants were given a five-item Likert scale (strongly disagree, disagree, neither agree nor disagree, agree or strongly agree) to choose from.

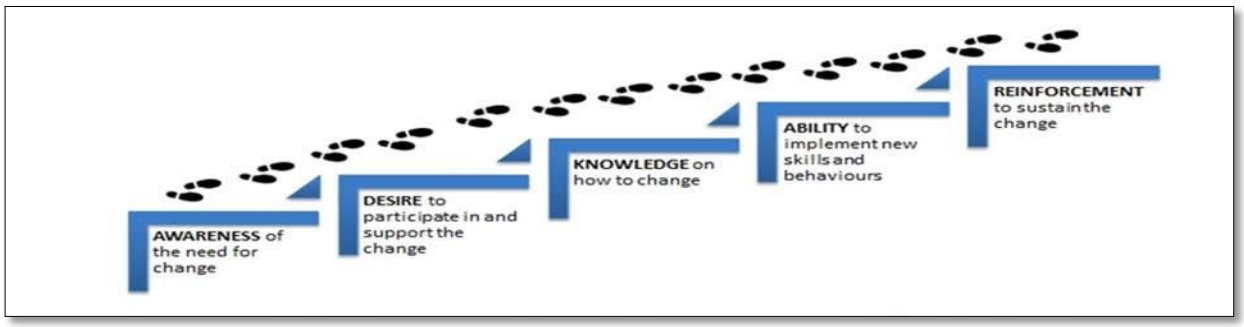

Figure 1: Key processes and five building blocks of ADKAR model (Lad, 2014)

Since many of the Medical School academic and senior staff are part of the school's committees and working parties, the MD project management curriculum team consulted and communicated with them heavily. Therefore, the academic and senior staff were asked to complete the survey first in December 2016. The professional and clinical school staff were asked to complete the survey in March 2017.

The authors contacted 52 academic and senior staff and 34 (65%) completed the change sizing survey. Of the professional and clinical school staff, 85 staff members were contacted and 44 (45%) completed the survey.

This survey was an opportunity for academic and senior staff to provide the MD curriculum project management team with their opinions and feedback on the MD curriculum renewal project and how they think it will impact them and their team. The results of the survey show that main issues/concerns that academic and senior staff identified are:

1. **Resourcing** (providing the staff and financial resources needed)
2. **Need for change**
3. **Complexity**
4. **Transition** (there is a need to provide more support in the transition years and to take fewer students in 2019 and 2020)
5. **Up-skilling of current staff** (providing training and support)

Professional and clinical school staff provided the MD curriculum project management team with their opinions and feedback on the MD curriculum renewal project and how they think it will impact on them and their team. The results of the survey show that main issues/concerns that professional and clinical school staff identified are:

1. **Resourcing** (providing staff and financial resources needed)
2. **Consultation and communication** (there is a need to provide regular updates)

3. **Challenges around the transition years and logistics of running two programs simultaneously** (such as questions regarding whether existing students will complete the program they started while new enrolments are doing the new program)
4. **Updating the curriculum after it has been implemented**
5. **Up-skilling of current staff** (providing training and support)

DISCUSSION AND LESSONS LEARNED

The findings of this survey can be useful to help senior leadership and stakeholders understand the magnitude of change and the issues and concerns of the staff. The results of this survey should be used to customise the project, the change management strategy and activities.

The ADKAR model works by assessing individuals on each of five building blocks in consecutive order for readiness to deliver successful change. This survey was an opportunity for staff to provide the MD curriculum project management team with their opinions and feedback on the MD curriculum renewal project and how they think it will impact on them and their team.

It was very clear from the survey results that the staff were welcoming of the proposed changes; however, resourcing, upskilling of staff, regular communication, updating the curriculum regularly and investing during the transition years (the period of phasing out current program and introducing the new program) as well as the logistics of running two programs simultaneously for the first four to five years after introducing the new curriculum were the key to the success of this change.

CONCLUSION

This research paper is a critical exploration of the welcoming and initiating of a curriculum change at the tertiary level through looking at the curriculum changes in the medical education provided by the Sydney Medical School at the University of Sydney, Australia. Changes within the education sector are a constant and a familiar component of higher education management. The nature of a curriculum review required stakeholder involvement on all levels and keeping staff informed and involved with the curriculum change project meant that staff were supportive of the change. Providing staff with the opportunities to up-skill current staff ensured that the staff were excited about learning new skills and they felt supported and less anxious about the proposed changes. In addition to this, planning ahead for adequate resourcing and the logistics of running the new program while phasing out the old meant all relevant stakeholders needed to be involved in the process and understand each other's roles better.

The authors found that staff were much more supportive of the change when they were involved in the change processes and had a say in the change process.

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REFLECTIONS FROM STAKEHOLDER ENGAGEMENT IN DEVELOPING A CURRICULUM FOR SUSTAINABLE RENOVATION

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Keywords: Stakeholders, sustainable, renovation, skills, installer training

Abstract

Installers with sustainable renovation skills are essential to deliver low carbon buildings. A performance gap often exists between the modelled expectation of reductions in domestic CO_2 emissions, and what newly renovated buildings achieve (Zero Carbon Hub, 2014). One reason for this can be poor detailing and workmanship by installers. In addition, householders have reported dissatisfaction with the levels of sustainable building expertise and advice offered by installers. Many installers work within the Repair, Maintenance and Improvement (RMI) industry as Small and Medium Size Enterprises (SMEs). Installers have been found to favour on-the-job training, however, without formal training the average builder can struggle to consider the 'whole-house approach' necessary for sustainable renovation, good air quality and minimising moisture risks. The findings discussed in this paper stem from a Leeds based workshop and following meetings, held to gather key stakeholders from local Government, developers, construction firms, charities, colleges and research. The aim was to develop course content themes for a pilot curriculum on sustainable building skills, which can be applied to the renovation sector. Existing training approaches were discussed, which could be further developed for SME installers to access on a wider scale. These included formal methods of training, which apprenticeship can now sit alongside, hosted at a college and on the job training. This paper discusses the key course themes arising which could address the sustainable renovation skills shortage within the RMI industry, reflecting on the different approaches.

INTRODUCTION

Buildings accounted for 34% of total UK greenhouse gas emissions in 2014 (CCC, 2015). There is a design-performance gap in energy consumption and carbon emissions from buildings in both sustainable renovation and new-build construction, partly due to a lack of technical understanding among construction project team members (Zero Carbon Hub, 2014). Furthermore, householders have reported challenges in finding adequately skilled installers to carry our sustainable renovation (Simpson, 2017). The lack of installer expertise in sustainable construction in the UK is partly because the construction processes involved require 'energy literacy' in all occupations, high levels of qualifications, multi-skilled people, integrated team working and effective communication (Clarke et al., 2016). Many installers work within the Repair, Maintenance and Improvement (RMI) sector within the construction industry and are Small and Medium Size Enterprises (SMEs), often general builders. Standardised training to

become a general builder does not exist, which has an impact on the ability of those individuals to take a 'whole house' approach to energy performance and related issues such as moisture movement and indoor air quality (Maby and Owen, 2015).

In order to deliver sustainable buildings which meet designed performance criteria in the UK, over 250,000 tradespeople need additional training (Maby and Owen, 2015). The construction industry requires new knowledge to be developed and transferred through a complex and fragmented supply chain (Peterman et al., 2012). Previous policy related to sustainable building has focused on the installation of individual technology 'measures', as oppose to considering the whole supply chain as a collective 'system' (Killip et al, 2018). A lack of energy performance-related training and knowledge is one area contributing to the performance gap (ZCH, 2014). Furthermore, culture and embedded behaviours are not always aligned to enable the delivery of designed buildings and teams may be unaware of the role they play (ZCH, 2014). The British construction industry has been described as having low skills and job insecurity due to casual and self-employment of many workers, low levels of initial training, the reliance on goodwill of contractors to take on trainees and the need to learn on-the-job (Clarke and Wall, 1998).

Installers have been found to prefer learning from experience or alongside skilled teachers (Maby and Owen, 2015). Apprenticeship routes enable apprentices to work alongside experienced staff, gain job-specific skills whilst they study (HM Government, 2018). Other European countries avoid on-the-job learning by running comprehensive and intense programmes of initial skill formation for all trades taking place within Colleges, in workshops and on sites resulting in workers with broad-based skills and abstract skills including maths, setting out, planning and controlling work (Winch and Clarke, 2010). The UK development of 'T Levels' may share some elements of this delivery by combining technical skills during the first year; T Levels are technical education programmes due to operate alongside apprenticeships for 16-19 year olds , shaped by industry and including structured placements (DoE, 2017). Construction is one of the three sectors to pioneer T Levels in 2020.

METHOD

The insights discussed in this paper stem from a workshop0F[1] held in Leeds during January 2018 and follow-up meetings on the themes of '*social value'* and '*building performance'*. These sessions gathered stakeholders from local Government, developers, construction firms, charities, colleges and research. The aim was to develop key themes for content for a pilot curriculum delivering sustainable building skills; one strand of which could be applied to the renovation sector. A pragmatic approach was taken in that attendees were selected and questions posed in response to the need to develop local training approaches to equip construction workers with sustainable building skills. Information was gathered using post-it notes and pro-formas completed by attendees and written notes taken by a research assistant. The project was informed by two research projects; GLIDER and TRUE. GLIDER (Governance of

[1] Workshop facilitated by Dr Alice Owen and Prof Paul Chatterton with research support from Dr Kate Simpson.

Low Carbon Innovation in Domestic Energy Retrofits) had previously identified a skills gap and lack of vocational skills training for construction workers involved in low energy retrofits. TRUE (Transformational Mapping for Urban Environments) explored ways in which key stakeholders can work together to deliver city-wide solutions to social and technical challenges, including sustainability and low skills.

Stakeholder insight

The workshop and meetings were used to identify what could be included in training to equip construction workers with sustainable construction skills, who should be targeted and how the training/development could be delivered and incentivised, summarised in Table 1.

Table 1. Summary of the skills needed, targeted individuals, course delivery and incentives for training (Simpson, Owen and Chatterton, 2018)

Theme	Building performance	Social value
Course content	Overview of climate change, CO_2 emissions from the building stock, comfort and health factors What building performance targets are trying to achieve: healthy buildings, cheap to run Practical issues /challenges: consequences of missing key 'principles' Continuity of insulation and avoiding thermal bridging Air-tightness and air-movement within the space controlling the internal atmosphere and within the fabric Measuring building fabric: thermal, moisture etc	Communication skills Awareness of other trades and the whole-process of build Respect of quality and building performance Vertical integration of supply chain and feedback loops Whole lifecycle of buildings Materials and how they affect construction practice, for example fast-setting Gypsum plaster needing fast work Collaborative procurement routes Digital technologies
Who should be learning	Builders / tradespeople for toolbox talks Managers for higher level top-up courses	All levels and roles / trades? Wider actors, for example funding bodies where social value tools are used. Clients/developers – how does this link to their own Corporate Social Responsibility / Sustainable Development Goal plans?
How the course should be delivered	Toolbox talks on site with whole team Online / virtual tools with pictures and quizzes One-week intense course Higher level for clerk of works /site manager with trade experience	National Vocational Qualification (NVQ) additions T-level courses (especially to build collaborative teams) Formal courses – to set expectations of all trades/enable understanding of all trades – integrated vertical chain Continuous learning should be promoted from the start Time on social enterprise projects as part of apprenticeship route
Incentives and Opportunities	Stringent targets, such as Passive House air-tightness levels enforced through Building Regulations Certifier and building control requirements, e.g. only employing work teams with training certificate 'Gold' Construction Skills Certification Scheme (CSCS) cards created & made essential for tendering Leeds funded projects League tables on building performance skills Leeds City Council required Demand for healthier houses	Fitting into existing training frameworks Soft landings scheme and linking building performance to social benefits Life-cycle mentality T-shape course developments

Whilst the *building performance* and *social value* course contents differ, there are commonalities. For example, providing training on whole-house building performance with a particular focus on creating healthy indoor environments would entail a social value to the occupants. Both areas of training are aimed at installers but require managers or supply chains to be informed in order for the installers' expertise to be deployed effectively. Social value was discussed primarily as a requirement for part of larger formal courses starting at initial vocational or T-Level training, as well as complementing continuous learning methods. The

building performance training, whilst key for new entrants to the industry was discussed more in terms of equipping existing installers with skills through toolbox talks or short intense training activities. The incentives and opportunities for each area of training could be driven through incorporating the methods into existing training or enforcing through Building Regulations and requirements to work on site, such as through Council legislation, or the need for 'Gold CSCS' cards, for building performance related work in particular. The output of well performing buildings in terms of delivering healthy indoor environments and creating social benefits could further incentivise training as consumer demand for such properties and communities increases.

To provide insight into where on-the-job training has worked in Leeds, two case studies were shared by the meeting attendees. Firstly, the site staff training scheme for the Stamford Brook project, during the construction of 700 cavity wall dwellings on a National Trust Estate, provided knowledge and skills for building low-carbon, air-tight dwellings. The training included thermal bridging detail with illustrative examples. This was provided as part of an exchange where those on site also provided their own ideas for how to improve buildability or reduce costs. This was reported as one of the major successes of the project; operatives found it interesting and useful (Roberts et al, 2005). Secondly, the housing charity Latch found that using an approach that integrated delivering social value into a renovation project of a Victorian terrace in Leeds, which resulted in better measured performance than a renovation of a neighbouring property of the same type carried out with Green Deal approved installers and measures (Gorse et al., 2017; Latch, 2014). The difference was reported to be due to the 'whole-house approach' taken by Latch and valuing the time needed to achieve good performance, whilst keeping material costs down (Gorse et al., 2017).

In construction, socially orientated approaches such as that undertaken by Latch are underrepresented in the construction industry and could be better used to address both skills and building performance challenges. They require leadership and changes to procurement practices to address the social issues whilst enabling skill development (Loosemore, 2015). This is because the value is primarily placed on social benefits, as opposed to profits. The UK now has a Social Value Act which requires those who commission public services to consider wider social, economic and environmental benefits before starting a procurement process (Cabinet Office, 2016). This could be used to incentivise further training of building performance and social value.

DISCUSSION AND CONCLUSION

This short action-focused project has explored stakeholder insights into the key themes to be included in course content for a pilot curriculum delivering sustainable construction and renovation skills. The workshop and meeting attendees recognised the need to equip construction and renovation installers with sustainability skills. This was particularly the case

for building performance detailing, which research has highlighted as a shortfall within UK construction teams (ZCH, 2014; Maby and Owen, 2015). This may have led to the theme becoming a focus within the social value of construction meeting. However, in order to incentivise training, communicating the social value of upskilling in this area and acknowledging householder demand for such skills (Simpson, 2017) may contribute to motivation to train.

The current apprenticeship route and upcoming T Level development offer an opportunity for new entrants into the industry to train in a way which installers have been found to prefer: on-the-job (Maby and Owen, 2015). However, this will not be enough to equip existing installers, many of whom are SMEs in the repair, maintenance and improvement sectors. It's estimated that there at least 250,000 work in RMI, and a substantial proportion of these are sole traders or SMEs (Maby and Owen, 2015). Toolbox talks and on-the-job training have been found to be successful, during the Stamford Brook project and by Latch in Leeds, in upskilling existing trades teams, so further funding and investment for such training programmes could be beneficial.

The discussion which naturally emerged from the workshop was fairly focused on building performance, which may be due to the expertise of those in the room or recent research on this topic. However, delivering sustainable renovated buildings includes consideration of materials, water use, integrating efficient power and heat sources and creating homes which people want to live in. The social value of construction meeting led to discussion on considering the whole lifecycle of the building, during both design and construction stage to aid understanding of materials used and processes involved. This area could be explored further in follow-up research.

Further research on the success of different training approaches, perhaps through pilot studies based in Leeds and further afield, would build on this work.

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REFOCUSING SUSTAINABILITY EDUCATION: USING STUDENTS' REFLECTIONS ON THEIR CARBON FOOTPRINT TO REINFORCE THE IMPORTANCE OF CONSIDERING CO_2 PRODUCTION IN THE CONSTRUCTION INDUSTRY

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Keywords: Carbon Footprint, CO_2 Production, Reflection

Abstract

The construction industry is the most significant contributor to the UK's CO2 emissions: responsible for an annual output of approximately 45% of the total. This figure highlights the critical role the industry must play in achieving the Government's CO2 reduction target. It is, therefore, incumbent on construction-related educators to emphasise this issue and explore ways in which it can be reinforced. Unintentional desensitisation has resulted in the term 'sustainability' becoming diluted within education; as a result, many students now see sustainability, particular ly CO2 production, as just another concept studied from a theoretical perspective. Consequently, many students fail to grasp fully its broader implications and how it should affect strategic environmental decisions about construction processes, technologies, and products. This paper presents the findings of a unique pedagogy and assessment strategy used with final year construction undergraduate degree students during a sustainable construction technology module. The approach involved students calculating their carbon footprint and reflecting upon and extrapolating their results to the UK construction industry. A random sample of commentaries acquired from student portfolios over four academic years was analysed using computer-assisted qualitative data analysis software. The content analysis showed how the students' reflections on their carbon footprints proved to be an enlightening experience. Terms such as "shocked by my footprint", "surprised at the findings", and "change in attitude" were frequent reflective comments. When students linked their findings to the construction industry, phrases such as "waste generation", "technologies", and "materials" were some of the critical concepts considered. By using their personal experiences as a benchmark, students were able to gain an increased level of understanding of the causes of CO2 production; they also found it more straightforward to relate these issues to the UK construction industry.

INTRODUCTION

The global environmental pressures on today's society are well-documented. Worldwide energy consumption continues to rise, resulting in a depletion of the world's resources and an increase in carbon emissions. The upper safety limit for atmospheric CO_2, considered to be 350 ppm, was exceeded in mid-1985 (CO_2Now 2014). Since then, atmospheric CO_2 has continued

to rise, and in July 2014, the concentration of atmospheric CO_2 had broken through the 400 ppm barrier and stood at 401.3 ppm (Scripps Institution of Oceanography 2014).

The construction industry is a significant player in energy use and CO_2 production. Buildings are thought to contribute approximately a third of global greenhouse gas emissions, mainly through energy generation using fossil fuels (United Nations Environment Programme (2009). Globally, the built environment is responsible for using approximately 3 billion tonnes of raw materials annually (United Nations Environment Programme [UNEP] 2012), which accounts for 35% of annual material consumption (CIOB, 2013). In the UK, this figure is closer to 45% (CIOB, 2010), which contributes to 13% of the total global CO_2 emissions (mainly from the embodied energy contained in materials production) with a further 32% of CO_2 emissions coming from the use of buildings (Gibson 2013).

The Department of Communities and Local Government (2013) has suggested that 40% of the UK's energy consumption is because of the way buildings are used. Riley and Cotgrove (2013) set this figure at nearer 50%, with 7% of energy use directly related to the construction process itself. The findings of the Low Carbon Construction Innovation and Growth Team (2010) advocated that the construction industry directly produces a total carbon footprint of over 300 million tonnes. However, Sharma et al. (2011) suggest that the UK construction industry is responsible for half of the energy consumption and CO2 emissions, and the operational phase of buildings contributes over 50% of greenhouse gas emissions and between 80% - 85% of energy consumption. It is acknowledged that these figures may vary by source; however, what is clear, is that the UK construction industry contributes significantly to the reduction of resource depletion through materials usage, waste generation and CO_2 emissions. The Climate Change Act (2008) is one of the most critical aspects of the UK Government's commitment to sustainable growth and the green agenda as it sets a target of an 80% reduction in CO_2 emissions by 2050 (based on the CO_2 levels from 1990). Given the impact the construction industry has on the environment, it is essential for the industry to consider areas where contributions can be made to achieve these ambitious targets.

This paper argues that the "sustainable" label has become diluted in construction-related education to be considered just another theoretical concept students need to learn. The paper, therefore, presents the findings of a study to examine the effectiveness of the pedagogical approach used in the final year of an undergraduate construction management programme to demonstrate how student perceptions of sustainability can be changed to enable them to form closer associations between sustainability and its impact on the construction industry.

HIGHER EDUCATION AND ITS CONTRIBUTION TO SUSTAINABILITY EDUCATION

The "Agenda 21" action plan, agreed at the 1992 Earth Summit in Brazil, was designed to deliver global sustainable development (Perdan, Azapagic and Clift 2000). It recognised environmental education as a key component in achieving sustainable development (Abdul-Wahab, Abdulreheen, and Hutchinson 2003). Acknowledgement of the importance of education was recognised in 2003 when The United Nations National Education, Scientific and Cultural

Organisation (UNESCO) declared 2005-2015 to be the "Decade of Education for Sustainable Development" (UNESCO 2003). In doing so, UNESCO proclaimed the key role of sustainability in teaching and learning (Dupuis and Ball 2013; Opoko and Egbu 2017). The UK Government followed this shortly after with its 2005 strategy document "Securing the future: delivering the UK sustainability strategy". Once again, this publication declared sustainability education had a vital role to play in equipping today's generation with the knowledge and ability to pursue sustainable development (Opoko and Egbu 2017).

Higher Education Institutions (HEI) have, as a result, become critical players in the delivery of knowledge to produce graduates who can influence sustainable practices and achieve the goals set by governments around the world (Karakzoglov, 2013; Longhurst et. al., 2014; Opoko and Egbu, 2017; Kapitulcinova et. Al, 2018). It is now widely accepted that much of the responsibility for sustainability education falls to universities (Jones, Trier and Richards 2008; Segalas, FerrerBalas and Mulder, 2010; Pappas, 2012). Indeed, Martin and Jucker (2005) argue that the most critical organisations in driving the sustainable agenda are universities.

While UNESCO's "Decade for Education of Sustainable Development" may have called for education to lead the way in developing sustainability knowledge and be fully integrated at all levels of education (Lambrechts et al., 2013), Karakzoglov (2013) posits that universities are critical partners to sustainable education. However, Higgins and Thomas (2016) argue that the position of sustainability education is not as prominent in the higher education curriculum as it should be. Where and how sustainability sits in universities' curricula has been discussed by Jones, Trier and Richards (2008). They argue that universities must ensure they provide the educational means by which graduates can meet the many challenges the sustainability agenda presents. As Hedden et al. (2017, pp. 2) succinctly explain, by offering courses which acknowledge environmental impacts and advance student learning: *"*universities can affect sustainability education and, thereby, the environmentalist cause.*"*

Theoretical Framework

A theoretical framework can be described as a theory which provides a lens through which a research problem is considered. It should be noted that seldom does one theory fit precisely with what a researcher is considering. As Anfara & Mertz (2006 p.xxvii) identify: *"*No theory, or theoretical framework, provides a perfect explanation of what is being studied." Therefore, in choosing a suitable theoretical framework, the aim is to adopt a theory which is considered the "best fit" to the research question being considered.

The theoretical framework which underpins this paper is the "threshold concepts" framework, which was first introduced in 2003 by Erik Meyer and Ray Land. At its core is the idea that in university programmes there are often concepts which can be difficult to understand and can be troublesome to students (Eckerdal et al., 2006). Meyer and Land theorised that this troublesome knowledge is often central to the understanding of a discipline (Lucas & Mladenovic, 2007). It is considered essential for students to understand these central concepts if they want to move forward in their programme and strive for mastery of their chosen subject

(Cousin 2006). Meyer and Land (2006) likened this understanding to the opening of a portal through which previously complex ways of thinking could be accessed and represented a transformation in understanding from which a student could progress. Once the transition had been made, students would experience phenomena within their chosen discipline in a different way.

This paper uses the threshold concepts theoretical framework in the context of "transformative learning" in sustainable education, with the premise that it will provide the opportunity for students to experience: "a significant shift in the perception of a subject" (Meyer and Land 2005, pp. 373). It is, as Meyer and Land (2005) posit, where critical moments of the educational experience are defined, and students begin to find new ways of comprehending their discipline. The five main characteristics shaping the threshold concepts framework are:

1. **Transformative**: Students make a substantial shift in their perception and understanding of a concept (Lucas and Mladenovic, 2007) and are an essential feature of the framework (Baille, Bowden and Meyer, 2013). The transformative process enables students to understand concepts within their discipline in a completely different way (Eckerdal et al., 2006).
2. **Irreversible**: Once something is learnt, it cannot be unlearnt, is the premise of this characteristic. Once a concept is genuinely understood it will take considerable effort for it to be forgotten. However, as Baille, Bowden and Meyer (2013) identify, gaining an understanding of something in isolation to other things may not be sufficient to serve one adequately forever. Learning is and should be, a continuous process.
3. **Integrative**: Students discover the interrelatedness of various phenomena. The interconnection between concepts, which may have hitherto been hidden, can be exposed to enable students to make a connection between the various concepts.
4. **Bounded**: Sometimes described as "boundary markers" (Eckerdal et al., 2006, pp. 103), this term describes the boundaries which delimitate a concept. Boundaries can be defined as frontiers of a concept which border with other concepts (Cousins 2006).
5. **Troublesome**: Eckerdal et al. (2006) describe this term as concepts which are potentially difficult to understand. Meyer and Land (2003) adopted this concept to describe situations where students struggled to comprehend concepts within their discipline. By tackling the relationship between theoretical knowledge and the context in which it is applied, then by reflecting upon their experience, students can step across the threshold of knowledge and develop a deeper understanding of their discipline.

State of Liminality

Meyer and Land (2005) describe the state of liminality as the place a person inhabits as they transition between stages of personal development. The "internalisation of a concept is likened to a journey or 'rite of passage' within and beyond a liminal space" (Baille, Bowden and Meyer, 2012, pp 229). It is these liminal states that students find themselves in as they attempt to understand the issues surrounding sustainability.

Sustainability Education and the Construction Industry

The UK Government's sustainability strategy identifies sustainability literacy as a core component for university graduates (HMG 2005). To be "sustainability literate" is to understand the requirements for environmental change combined with the knowledge and skills to contribute to this change (Murray et al., 2007). Sustainability education will, therefore, provide students with an appreciation of how their actions will impact in the broader society and provide them with the sustainability literacy required in their professional career (Opoko and Egbu 2017). Sustainability education will assist students in developing skills in critical thinking, and problem-solving, to become sustainability literate, and to prepare them for the challenge sustainability brings (Hedden et al., 2017). Higher education must educate students to understand what sustainability means and to empower their thinking and approaches to solving sustainability problems (Pappas 2012).

Threshold Concepts Framework and Sustainability Education

This paper argues that the term "sustainability" has become diluted within construction education and that many students now see sustainability, particularly CO_2 production, as just another concept to be studied from a theoretical perspective. Consequently, many students fail to fully grasp its wider implications on the construction industry which presents them with "troublesome knowledge". By adopting the pedagogical approach to teaching sustainability that is presented in this paper, it is argued students can discover the interrelatedness of their CO_2 production and that of the construction industry. Further reflection on both creates the opportunity to identify boundaries to knowledge, where they overlap, but importantly, question the concepts to push these boundaries forward. Finally, they transform their understanding of these concepts to develop a deeper understanding of their contribution to sustainability issues and the importance to the industry. Once these concepts are learnt, they cannot, without great effort, be unlearnt and so, this knowledge and understanding are taken with them into their professional careers.

Sustainability Education for Construction Students

The sustainability issues regarding the environmental, social and economic impacts of the construction industry are significant, both in the use of natural resources during the construction process and resource consumption of the final building (Graham 2000: Zuo and Zhao 2014: Murray & Cotgrove 2014). Indeed, Higham and Thomson (2015, pp 417) argue that *"Sustainability represents the UK construction industry's most important and challenging issue".* To meet these challenges, construction professionals need to have the necessary skills and

knowledge to respond to them (Murray and Cotgrove 2014: Opoku and Egbu 2017). The Government's industrial strategy of 'Construction 2025' (BIS 2013) has a sustainable construction as one of its key objectives demonstrating the need to improve the environmental performance of the UK construction industry thus making sustainability education a foundation in construction education (Murray and Cotgrove 2014).

Sustainability education for the engineering disciplines is critical given the impact their work has on the environment (Abdul-Wahab et.al.2003), particularly given the importance placed by employers on graduates who are sustainability literate (Opoku and Egbu 2017). The delivery of sustainability in practice and sustainability literacy, therefore, requires a change in awareness and increased engagement in construction professionals (Higham and Thomson 2015).

PEDAGOGIC APPROACH TO SUSTAINABILITY EDUCATION

Active Learning

This study adopted a constructivist learning approach where students construct knowledge from experience and by reflecting on this experience (Scott and Ghosh, 2016; Hedden et al., 2017). An active learning pedagogy is implemented to empower students with responsibility for their learning (Petty, 2004) and encourage them to interrogate critically a range of alternative options from which to conclude (Deshpande and Salman, 2016). The process, therefore, embraces the principle of rather than just listening to or reading content, students learn by doing and make sense of their ideas (Kapitulcinova et al., 2018). Segalas et al. (2010) argue that traditional methods of teaching sustainability are inappropriate and that students' sustainability knowledge can be enhanced using a more constructivist, active learning approach. By actively constructing knowledge, rather than just passively acquiring it from teachers, students can shape their learning (Lee and Hannafin, 2014; Hedden et al., 2017). Hayles and Holdsworth (2008) have stated that when students can focus on their lifestyles, they develop a deeper understanding of sustainability issues and the impact on their professional choices.

METHODOLOGY

The Carbon Calculator

The carbon calculator was the teaching approach used to enable students to understand the environmental issues faced by the industry in which they will be working. Firstly, it encourages students to understand their carbon footprint and what influences it and then link it to the construction process and product. Secondly, it reinforces the environmental issues faced by the construction industry by requiring students to evaluate their carbon footprint. And thirdly, it requires students to relate the outcomes of the calculation to the construction process and product to enable them to understand and reinforce the issues faced by the industry.

The study was contextualised in a final year undergraduate construction technology module. A large part of the syllabus for the module focuses on sustainability about the construction of buildings and their final use. The part of the syllabus considered during this study is called "calculating your carbon footprint". As part of the syllabus, students are introduced to a freely accessible online tool which allows them to input data about their lifestyle (http://www.carbonfootprint.com/calculator.aspx): including data relating to their energy bills, travel arrangements, shopping habits and household.

Students are required to complete the carbon calculator exercise several times (based on different situations) to ensure they have sufficient data to compare. Examples of different situations students use include living at their parental home, living away at university and, where relevant when they were on a year-out industrial placement. The online tool is introduced to students in a seminar and each section explained. This process enables students to note the various types of information required to complete the online tool, which they can then collect before undertaking the exercise. Students are then tasked to gather their relevant information and complete the online exercise within a three-week period. As part of the module assessment strategy, the students are required to present their results, offer a discussion and comparison of their data, and relate it to the broader construction industry about how their results may influence their approach to the construction process. The final part of the exercise is for students to reflect on their findings and whether it has increased their understanding of sustainability issues, if it has influenced their thinking in the broader topic area, and more specifically, shaped their future approach to dealing with sustainability in the construction process.

The exercise has been used in the module for several years. The data used for this study are based on four consecutive years, i.e., 2013/2014 to 2017/2018.

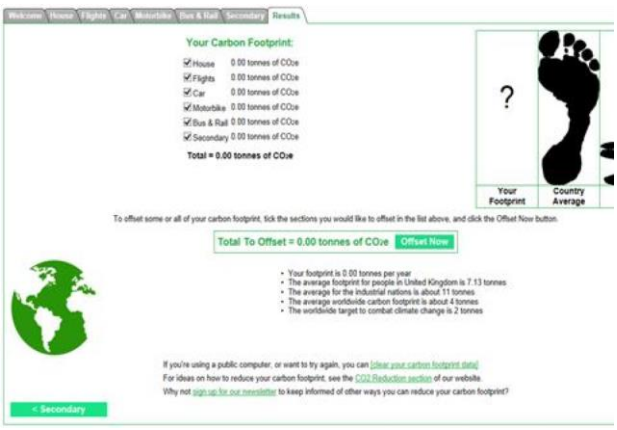

Figure 1. Final screen of Carbon Calculator collating all information entered and giving final personal carbon Footprint. (http://www.carbonfootprint.com/calculator.aspx)

Figure 2. Section of Carbon Calculator as asking for details of energy usage. (http://www.carbonfootprint.com/calculator.aspx)

Content Analysis of Student Reflective Commentaries

Content analysis is a research technique for the objective, systematic, and quantitative description of the manifest content of communication (Berelson 1952: 18). Bryman (2016), Elo et al. (2014), and Hsieh and Shannon (2015) have explained it is a flexible technique that can be applied to a variety of different media but is predominantly used to analyse text. Large quantities of text can be studied using content analysis: ranging from the simple counting of words to generate word frequencies (Bryman 2016), to coding and the detailed correlational examination of language (Weber 1990), and finally, to classification and categorisation of themes to provide a comprehension of the phenomenon of the study (Downe-Wambolot 1992).

Content analysis of the past four years of portfolios submitted by students taking the construction technology module was undertaken using NVivo 11 Pro. The analysis commenced with a word frequency query and progressed to a text search query of keywords and labels. The written reflections of the students contained in the portfolios were classified and categorised to themes identified from the literature review to provide a comprehension of the focus of the study

This paper aims to analyse the pedagogical approach used to teach sustainability on a construction-related undergraduate degree programme. It seeks to demonstrate how such an approach can foster a greater understanding of sustainability among students, improve their sustainability literacy, and enable them to form close links between sustainability issues and the construction industry in preparation for their industrial career.

Sustainability as a Diluted Topic

The principle tenet in this paper is that sustainability, as a topic, has become diluted and is viewed by many construction students as just another theoretical topic they must study, without fully appreciating the relevance to the construction industry and their future career. The qualitative analysis of student portfolios appears to support this viewpoint. The critical aspect is a dawning awareness of the impact the construction industry has on the environment. Students cited how their lack of understanding and awareness of the impact buildings have on the environment had changed following the module.

> "[. . .] has shown me how important sustainability is in construction - the issues will not disappear."
>
> "I can now see how construction plays a major part in the UK's carbon footprint."
>
> "I would not have understood or considered the issue of sustainability where it not for the module."

Many people see construction as a cost or profit dominated industry, so it was particularly interesting to see comments discussing costs about sustainability. One student suggested that profitable businesses can also be sustainable.

> "I can now see the construction industry not just as a profitable business but also, potentially one day, a completely sustainable industry."

While another acknowledged the importance of "client buy-in" to sustainability recognising that:

> "[. . .] clients need to understand that although some technologies have high initial cost, they could reduce expenditure for them in the future."
>
> "[. . .] before I did not have an appreciation of the true value of whole life costs."

Although sustainability has been a discussion point for many years, the first real significant global addressing of the issue was the Brundtland Report in 1987, followed in 1992 by the Kyoto Protocol (1992). Since then, sustainability has grown in prominence, particularly in the construction industry. However, despite this, there was a distinct lack of awareness among students of sustainability being a "real" issue for the construction industry. The following comments from two students demonstrate this view and support the argument that sustainability in construction education has been diluted to the point that students are unaware of the important position it occupies in the construction industry.

> "This module has opened my eyes to the industry's significant contribution to climate change."
>
> "Sustainability, I feel, is something that has not been talked enough about in industry in the past: it is not something you focus on while on site."

Development of Themes

During initial coding of the data, several themes began to emerge. Further coding distilled these into the following three central themes: learning and teaching, connecting learning to the construction industry, and career development.

Learning and Teaching

The use of the carbon calculator software as a tool for active learning proved extremely useful in highlighting the issues around CO_2 production and provided a catalyst for the students to explore this in more detail:

> "By analysing our personal use of carbon, we can understand the enormity of the task faced by all industries in tackling the sustainable agenda."
>
> "I feel that the use of a carbon calculator [. . .] has been very enlightening to me."
>
> "The carbon calculator [. . .] makes you realise what the most carbon-intensive areas are."

The first step of using the carbon calculator in the assessment also helped students to start to challenge current practice and look for alternative environmental options when producing buildings. In the course of this, it also enabled them to develop essential employability skills, such as problem-solving and critical analysis, and, as a result, they begin to challenge their baseline thinking.

> "I have learnt to challenge and critically evaluate the technologies and materials used in construction projects and understand their contribution to the environmental performance and sustainability of the building."

> "By improving my knowledge of these areas, and modern sustainable technologies and materials have allowed me to challenge the norm and the current methods used in the industry."

> "The assessment has helped me to understand and be able to appraise construction technologies critically."

The module assessment was explicitly designed to offer an alternative pedagogical approach to improving student' sustainability literacy about the construction industry. However, it is worth noting how the carbon calculator exercise has had a personal impact on them and encouraged them to look at ways of reducing their carbon footprint.

> "During analysis of my carbon calculator results, it became evident that I must strive to improve certain areas of my lifestyle to live more sustainably."

> "By being aware of the impact my daily actions have on the environment, and by making small changes to my lifestyle, I can see it is possible to have a smaller carbon footprint to help save the environment."

> "[. . .] the module has given me an appreciation of how my actions can influence the production of carbon emission. In the past, I did not recycle, but now recycling is a part of my day-to-day life."

> "When I think back to my carbon calculator results, I can see the impact recycling materials and changes to my lifestyle choices will help to offset my carbon footprint."

One part-time student, on discovering her carbon footprint said: "This has shocked me" and was so taken with the thought-provoking results the carbon calculator produced, encouraged work colleagues to complete it and think about their carbon footprint.

> "As I was surprised at my carbon calculator results, I thought I would survey five operatives on site to see what their carbon footprint was. Four out of the five had a carbon footprint higher than the UK average. Generally, they were all shocked at their level of CO_2 they produced."

The pedagogical approach to active learning using the carbon calculator provided students with a unique opportunity to experience phenomena differently. By placing the focus on their lifestyles, they developed a deeper understanding of CO_2 production, causing a significant shift in their perception of these issues and developing their sustainability literacy.

Linking Learning to the Construction Industry

Having introduced the concept of CO_2 production through focussing on their personal lives, students, in the next stage of the assessment, were required to reflect on this experience and use their learning to develop an understanding of how this may impact on the construction industry. The purpose of this was to enable students to use their "new" sustainability literacy to transfer it across the programme into other modules. Students were using their transformative experience from one module and seeing the interconnectedness to other parts of their programme, using their knowledge to inform decisions on other modules.

> "When I reflect on my knowledge acquired from the carbon calculator, my results influenced the environmental choices, technologies and materials I have used in my building project assessment."

> "I used my carbon calculator results to analyse the technologies in the buildings to understand their sustainable credentials; this influenced my design choices for my professional practice project."

Students began to focus on specific construction-related issues such as materials choice, with a recognition that the embodied energy, particularly CO2 production, can have a significant influence on materials choice.

> "[. . .] informed decisions about the specification of materials are needed with consideration given to the environmental impact of the materials, namely the embodied energy they contain."

> "The module and assessment have made me aware of the environmental and economic costs of sourcing raw materials, manufacturing and delivery."

> "It has given me the knowledge to influence the building design to source sustainable materials and bring new technologies to a project to reduce carbon emissions."

There was also a recognition that all stakeholders in the construction process had a responsibility to address sustainability in the industry.

> "The design and planning of a new building should consider the costs to the environment and what are the most energy-effective materials to use in the building."

> "There is often a conflict of interest between the parties interested in a new building. The bottom line involves balancing the building cost with the performance of the building while considering the payback in value/rental terms for the owners/financiers."

> "I now understand that it is important to consider the lifespan of a building and how an upfront investment in materials and technologies can benefit the environment and stakeholders in the long run."

One area to feature prominently in student reflections, and as a direct result of the carbon calculator exercise, was that of recycling and waste management. Students recognised this as a critical aspect of on-site construction practice and the importance of proper site management in this area.

> "[. . .] within the industry, we still factor in a degree of waste that we just accept as the norm."

> "If I could have any influence on the building project from my results, I feel that one of the focuses should be on the strategic and proper waste management of materials on site."

> "Not just in construction, but in the UK, we need to think about reusing buildings and materials, be that refurbishing buildings or recycling building materials."

One section of the carbon calculator focuses on personal energy use. Many students were able to relate this to the energy performance of buildings.

> "The carbon footprint calculator exercise helped me to identify that one of the most sensitive areas of decision making is the energy consumption from the building."

> "The results enabled me to identify the energy performance issues which affect the energy efficiency of the building and identify methods and assessment tools that can be used to improve building energy performance."

One part-time student reflected on their company's practice in this area to improve their building's energy efficiency performance.

> "I aim to take the progress my employer has made into schemes by aiming to exceed the BREEAM target of 'very good' to achieve an 'excellent' rating."

The analysis of student reflections demonstrates how they have successfully translated their carbon calculator results into specific construction related issues. There is an explicit recognition of the critical environmental issues facing the construction industry and where the focus needs to be in addressing them. As future construction managers, they have identified the importance of proper management in the operational issues with which they will be involved such as materials management and technologies. However, there is now a greater appreciation of broader issues such as design for energy efficiency and materials specification. These may be areas in which they have limited influence, but with their increased sustainability literacy, they can make a significant contribution to addressing the environmental issues which face the industry and with them, as future construction professions, must deal.

Career Development

The literature on sustainability education identifies the importance of future construction professionals having the necessary sustainability literacy to tackle the environmental challenges facing the construction industry (Murray and Cotgrove, 2014; Hedden et al., 2014; Opoku and Egbu, 2017). The final part of the assessment asked students to discuss how they could take it into their career as future construction managers.

Having increased their sustainability education, the students were able to recognise the importance of using their knowledge to educate others, which was pleasing to see. Just as the part-time student referred to earlier encouraged their colleagues to calculate and address their carbon footprint, future sustainability literate construction managers can influence the practice of others and help them meet the environmental challenges faced by the industry.

> "[. . .] with this knowledge, the industry can deliver projects that meet clients' requirements, advise on environmental issues, educate others, and contribute to sustainable construction."

> "There is a need for the teaching of sustainable technologies and materials to educate up-andcoming site managers with the knowledge to be able to have an impact on the environment."

> "[. . .] site managers require the knowledge to be able to have an impact on the environment."

Decision making is one of the critical skills of a construction manager, so it was interesting to see students recognising that their sustainable literacy would enable them to make decisions in their management role, informed through their learning in this module.

> "When I start working in the construction industry, I will be able to make informed decisions when I speak with the client to make recommendations."
>
> "I feel that the portfolio has given me the opportunity to become a well-informed construction professional of the future who can make a positive impact on the environment."

There was an explicit acknowledgement of the sustainability challenges faced by the construction industry and a recognition that the industry cannot carry on as they are and more needs to be done to address these challenges.

> "It is important to re-think what they are doing as far as sustainability is concerned – rather than continuing to do traditional methods of work in unsustainable ways."
>
> "If I do not increase my knowledge and understanding of the main sustainability issues, I am likely just to follow traditional construction methods."

Having realised that the industry faces real environmental challenges, students acknowledged that their learning in this module had prepared them to face these challenges when entering the industry as graduate construction managers.

> "To change the industry, and its mentality regarding sustainability, it is going to take knowledgeable, open-minded professionals to challenge current methods. Learning about the sustainability issues in this module will allow me to do this in my future career as a professional."
>
> "The assessment has helped me to understand and be able to critically appraise construction technologies so that in my future career, I will have an appreciation of environmental performance issues and how technology can influence and overcome these issues."
>
> "I now feel much more educated, confident and excited to get out into the industry and put these techniques into practice."
>
> "As a future graduate going out into the construction industry, this module has prepared me for future changes in legislation and government regulations."

CONCLUSIONS AND RECOMMENDATIONS

This paper has described the pedagogical approach to sustainability education for future construction professionals on an undergraduate construction degree programme. Using an active learning, constructivist approach to teaching and learning, as advocated by Segalas et al. (2010), Lee and Hannafin (2014), the module centred the learning on students' lifestyles regarding their CO_2 production, enabling them to develop a deeper understanding of sustainability issues as stated by Hayles and Holdsworth (2008).

Reflection on these results, and further reflection on how they apply to the construction industry—thus, demonstrating Dee Fink (2007) and Petty's (2004) approach to active learning—was designed to reinforce their learning and encourage them to think about the sustainability challenges facing the industry into which they would soon be entering. What is clear from the analysis is that the carbon calculator exercise proved to be a significant catalyst for their sustainability education and improving their sustainability literacy, which is aligned to Deshpande and Salman's (2016) work.

Reflection is an essential aspect of learning and students were encouraged to reflect on what they learnt at each stage of the process, as identified by Kapitulcinova et al.'s (2018) "learning by doing" and "making meaning of their own ideas" viewpoint. Consequently, there was much surprise and, in some cases, shock at how their carbon footprint compared to that of the UK average, with some students vowing to make significant lifestyle changes to reduce their contribution to CO2 levels. The exercise can, therefore, be deemed a success in itself if it encourages individuals to consider their contribution to environmental issues.

The primary purpose of the exercise was to encourage a more profound understanding of the environmental challenges faced by the construction industry and, as future construction professionals, their place in addressing them. Key results from this exercise are as follows:

1. a realisation that sustainability is not a theoretical topic to be studied at university but a realworld problem that must be addressed;
2. a more precise understanding of the impact the industry has on the environment;
3. acknowledgement by students that there are challenges faced by the industry, and these challenges are real, and they will bear some responsibility to address them;
4. a recognition that student learning on this module has equipped them with the knowledge to meet these challenges and influence the way the industry impacts on the environment;
5. by focussing first on a student's lifestyle, learning can be reinforced, and a deeper understanding of sustainability can be achieved; and
6. a demonstration that an action learning, constructivist approach to sustainability education can create a successful student learning experience.

In conclusion, it is acknowledged that students, as future construction-related professionals, need to understand that sustainability is a real-world issue. As stated by UNESCO and the Government, sustainability education and literacy are crucial to meeting targets set by international agreements to reduce carbon emissions. The learning, teaching and assessment strategies used by HEIs need to recognise that if students are to tackle the challenges they face on entry to the industry, pedagogic approaches need to focus on environmental lifestyles and reflection to reinforce their learning and their future application as a professional.

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Sustainability theme

CREATING BEHAVIOURAL ENGAGEMENT PROGRAMMES THAT WORK: A CASE STUDY FROM THE U.S. WEATHERIZATION ASSISTANCE PROGRAM

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Keywords: energy conservation; behavioural engagement; Community-Based Social Marketing

Abstract

Community-Based Social Marketing was used to design a programme to engage the clients of a Weatherization Assistance Program offered by the Energy Resource Center (ERC) in Denver, Colorado, U.S.A. The goal of the study was to identify promising behaviours for inclusion in the programme and strategies for changing these behaviours. The study included: 1) literature review; 2) interviews with ERC staff, 3) surveys mailed to ERC clients and 4) in-home interviews conducted with ERC clients. Previous research and data collected with ERC clients were used to evaluate the penetration, probability and impact of possible energy-saving behaviours. The results revealed that drying full loads of laundry, hang drying laundry, washing laundry in cold water, and using window coverings to control solar gain were high priority behaviours. Mid-priority behaviours that were also included in the engagement programme included: employing temperature 'setbacks,' reducing temperature setpoints through the use of clothing and blankets to control comfort, and keeping windows closed. Strategies for targeting these behaviours were developed based on the barriers and benefits for each behavioural target. This case study illustrates how Community-Based Social Marketing (CBSM) can provide a systematic approach to developing and implementing resident engagement programmes.

INTRODUCTION

A variety of negative outcomes including extreme weather, species extinction, and major health issues (National Climatic Data Center, NCDC, 2013) are projected to result from current and future greenhouse gas (GHG) emissions. The U.S. is responsible for 15% of GHG globally, and energy use is one of the primary sources of these GHG emissions (Boden, Marland, & Andres, 2017). For example, approximately 20% the U.S.A.'s carbon emissions result from residential energy use (U.S. Energy Information Agency, EIA, 2015a). Among residential energy users, low-income households consume more electricity per square foot than other income segments, often because these homes are in need of weatherization(Enterprise, 2009). This is both an environmental and social justice issue, with 31% of American households reporting in 2015 that paying energy bills or sustaining adequate heating/cooling in their home is a challenge (EIA, 2015b).

Weatherization Assistance Program

For more than 40 years, the U.S. Department of Energy (DOE) has funded assistance programmes, including the Weatherization Assistance Program (WAP) that aim to lower

residential energy use (DOE, 2016). The WAP distributes funding to state and local governments who provide free energy efficiency upgrades to low-income, disabled, and/or older adult residents within their communities (DOE, 2016). In Colorado, the WAP is administered through the Colorado Governor's Energy Office (CGEO). The WAP provides a variety of services to clients such as energy audits, compact fluorescent bulbs, air sealing, home insulation, furnace safety testing/repair, refrigerator replacement, and window/door replacement (CGEO, 2016). The extent of the services each home receives is dependent on a home energy use assessment.

WAP and Energy Use Education.

Nationally, the WAP has saved programme participants approximately $5.2 billion on their energy bills. These lifetime energy savings are equivalent to 2.2 million households' energy use over a year (DOE, 2016). As described, savings are attained by changing physical aspects of the home, with little to no occupant engagement. However, past research gives a few examples of the savings that can be achieved when WAP services are combined with customer energy use education programmes. For example, the education programme used in the NMPC Power Partnerships Pilot highlighted lowering water heater temperature, thermostat use, lighting, and electronics usage (Apprise, 2002). The education groups showed a significantly higher (26%) energy reduction compared to the group receiving WAP services alone (16%; Apprise, 2002). Similar results were obtained by Ohio's WAP (Gregory, 1992) where clients' behavioural preferences regarding comfort and convenience were taken into consideration during in-home visits. The WAP alone group experienced a 15% energy reduction whereas the education groups saved 21%. These savings were significantly different and persisted for three years (Gregory, 1992).

Outside of the WAP realm, other behaviour change programmes have promoted energy conservation among low-income residential customers. For example, Hall, Romanach, Cook, and Meikle (2013) engaged Australian citizens in adopting energy efficiency behaviours. Their face-to-face monthly meetings with residents delivered an energy saving programme which highlighted benefits outside of financial savings (e.g., comfort and social wellbeing) that could be derived from energy saving behaviours. Clients participating in face-to-face discussions showed the most behaviour change and were more likely to adopt long-term curtailment behaviours. However, an important element that has been lacking from these efforts is a systematic approach to developing and implementing resident engagement programmes. Community-Based Social Marketing (CBSM) provides such an approach.

Community-Based Social Marketing

Community Based Social Marketing (CBSM; McKenzie-Mohr, 2013) is a data-driven process for promoting behaviour change that has been used to create a variety of health promotion and sustainability programmes around the world (e.g., the Chuyen Que Minh campaign to reduce insecticide use on farms in Vietnam, and the WaterEfficient Durham programme to reduce residential lawn watering in Ontario, Canada; McKenzie-Mohr, Lee, Schultz, & Kotler, 2011). One of the premises of CBSM is that each context requires a unique approach. CBSM provides a process for developing that customized solution within each context. CBSM programmes are

successful because they utilize elements validated by social science, such as the theory of planned behaviour (TPB; Azjen, 1991) and persuasion research (Cacioppo & Petty, 1989).
There are several steps in the CBSM process. In CBSM we begin by clearly defining the goal of the project (e.g., are we trying to achieve reduced GHG or monetary savings?). We then examine the behaviours that are related to this goal. For example, changing the time of day when residents use their tumble dryer can result in monetary savings for customers on a time of use rate schedule, but will only impact GHG if usage is synchronized with the availability of renewable resources. To determine which behaviours have the greatest chance of success, we evaluate each behaviour on three criteria: a) ***impact***, or the strength of the relationship between the individual behaviour and the project's goal (e.g., hang drying clothes saves more GHG than washing in cold water), b) ***probability***, or the likelihood that the target audience will engage in the behaviour and c) ***penetration*** of the behaviour (i.e., how common is the behaviour currently?).

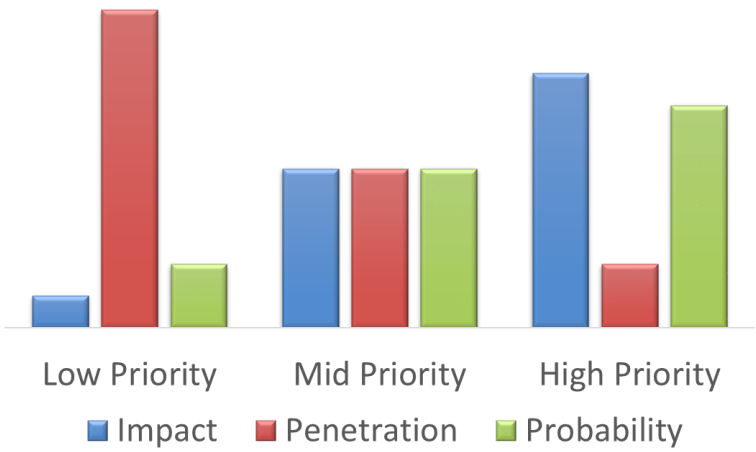

Figure 1. Using impact, penetration and probability to select behavioural targets.

We strive to select behaviours that combine high impact, high probability, and low penetration (Figure 1). When selecting behaviours, it is important that they be nondivisible (McKenzie-Mohr, 2013). For example, increasing a home's insulation is a divisible behaviour (Mckenzie-Mohr, 2013) because insulation can be added to the attic, external shell, or basement. These are different behaviours and as such, could vary in their barriers to adoption. Once the most promising behaviours have been selected, we identify the unique set of barriers and benefits for each target behaviour: What obstacles stand in the way of engaging in the behaviour? What motivates individuals to undertake the behaviour of interest?

The behaviour change programme is designed by matching this information to effective behaviour change strategies that will address both barriers and benefits (McKenzie-Mohr, 2013). For instance, past research might illustrate how barriers were successfully overcome by changing attitudes, perceived control, and subjective norms (elements of TPB). Finally, in order to maximize the effectiveness of the programme, programmes are piloted and evaluated. Piloting a programme allows us to confirm the effectiveness of the behaviour change intervention being proposed before implementing it on a wide scale, which could save countless time and resources if a programme is ineffective.

METHOD

Case study

In Colorado, WAP clients achieve 15% energy savings on average (personal communication, CGEO, 2015) which is consistent with the savings reported by the WAP-only programmes in Gregory (1992) and Apprise (2002). The goal of the current project was to use CBSM to design a resident engagement programme that could increase clients' energy savings.

ERC Services/Staff Overview.

The Energy Resource Center (ERC) is a nonprofit WAP provider in Colorado which participated in the case study. ERC staff fall into several different categories. ***Client Services*** personnel process client applications, schedule work, and handle service calls/complaints. ***Auditors*** make the first visit to the client's home. Auditors conduct home energy use assessments to determine what services will be cost effective for each client's home. If it is determined that insulation is needed, the client will receive a visit from the ***Weatherization Crew*** whereas HVAC repairs and replacements are completed by ***HVAC technicians.*** Once all the recommended work has been completed, a ***Lead Auditor/Inspector*** will visit the home. Completing the entire ERC process can take several months, depending on the recommended services.

A mixed methods approach was taken in the present project (see Figure 2) which included interviews with ERC staff (N=14), surveys mailed to ERC clients (N=76) and inhome interviews conducted with ERC clients (N=10). This approach was well-suited to the project because penetration of potential behaviours is best obtained in surveys, whereas qualitative methods elicit more information about barriers and benefits.

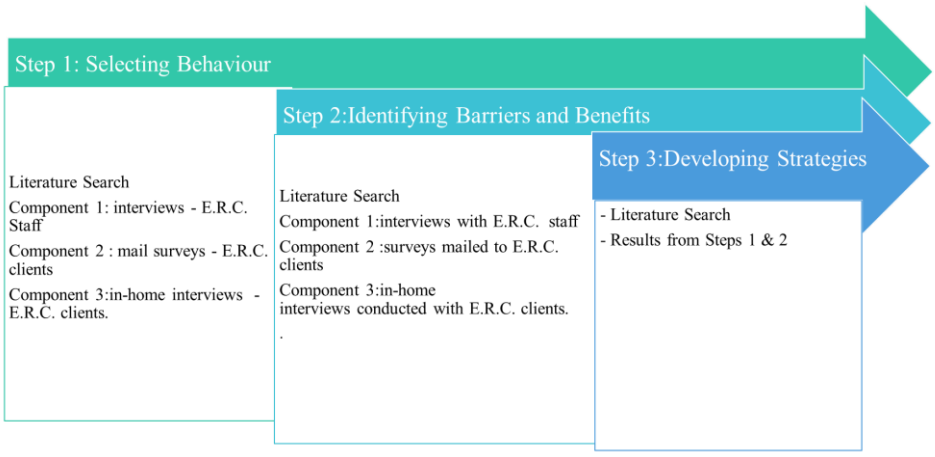

Figure 2. CBSM strategy employed in the ERC case study.

A survey was mailed to participants who had completed the ERC weatherization process (45% response rate). The survey included questions tapping probability and penetration of a variety of energy behaviours as well as perceived control over energy use behaviour, energy use behaviour norms, and level of customer engagement with the weatherization process. The survey items were based on a national evaluation of WAP effectiveness (Tonn & Hendrick, 2011). A subset of the survey respondents participated in a semi-structured interview in their homes. We asked these participants to walk us through their homes to observe their energy use behaviours. Questions focused on behavioural routines (e.g., leaving home) and willingness

to change their behaviours. Behaviours and verbal responses were coded and analyzed for current behaviour and probability of adoption of new behaviours, as well as barriers and benefits behaviour change. Because introducing client engagement required organizational change, ERC staff were also interviewed. A list of staff, current job title, and contact information was provided by the ERC and 14 staff representing every level of the organization were randomly selected to be contacted for an interview. Each job category had a corresponding interview protocol that was designed to tap the level of client engagement practiced within the organization (e.g., what energy saving behaviours does ERC promote?). Barriers to changes in the service delivery model were also assessed. Finally, scientific literature was used to determine impact and to supplement probability data obtained from ERC staff and clients. For more details about the various methods, please see Sandoval (2017).

RESULTS

Selecting behaviours and intervention strategies

Based on previous research the following behaviours were evaluated for inclusion in the project: drying full loads of laundry, hang drying laundry, washing laundry in cold water, using window coverings to control solar gain, employing temperature 'setbacks,' using clothing and blankets to maintain comfort at reduced heating temperature setpoints, keeping windows closed, using programmable thermostats, decreasing hot water heater temperature, and eliminating portable space heater usage.

Using programmable thermostats was not included in the intervention because interviews with staff revealed substantial organizational barriers to implementation. Specifically, a majority of ERC staff endorsed the belief that programmable thermostats were too difficult for clients to operate successfully. In contrast, ***decreasing hot water heater temperature*** was excluded from the engagement programme because the staff reported that this was already part of their standard set of services and well-received among clients. Information about the impact, probability and penetration for the remaining behaviours is provided in Table 1.

Table 1. Behavioural selection criteria

Behaviour	Impact	Probability	Penetration	Priority
drying full loads of laundry	High (BCHydro, 2017)	High (Hall et al., 2013)	Low (survey)	High
hang drying laundry	High (Spark Energy, 2012)	Low-Mid (Reaves et al., 2016)	Low (survey)	High
washing laundry in cold water	High (Plappally, & Lienhard, 2012)	Mid-High (interviews; Frantz et al., 2016)	Low-Mid (survey)	High
adjusting window coverings	Mid (DOE, no date)	High (interviews; Reeves et al., 2016)	Low (interviews)	High

Closing windows	High (Reeves et al.,2016)	High (interviews, Langevin, Gurian, & Wen, 2013; Mirosa, Lawson, & Gnoth, 2011);	Mid	Mid
reducing temperature setpoints	High	Low-Mid (interviews; Reeves et al., 2016)	High (survey & interviews)	Mid
Setting back temperature	High (EhrhardtMartinez, 2010; Urban & Gomez, 2012)	Low-Mid (interviews; Carroll, & Berger, 2008; Langevin et al., 2013)	Low-Mid (interviews)	Mid
Eliminating space heater usage	High	High (interviews; Carroll, & Berger, 2008)	Low (survey & interviews)	Low

Laundry behaviours. Drying full loads, hang drying and washing in cold water all demonstrated ideal combinations of penetration, probability, and impact. These were identified as high priority behaviours and were included in the intervention.

Drying full loads. Clients in the ERC programme were given magnets to place on their tumble dryers reminding them to dry full loads. A prompt was considered a good option because prompts are particularly effective when 1) they target a relatively simple behaviour, 2) they are placed in close proximity to the behaviour, 3) the behaviour is repetitive, and 4) the person is positively disposed toward the behaviour (McKenzieMohr et al., 2011).

Hang drying. Low-income households in the U.S. express only a low to moderate willingness to hang dry clothes (Reaves et al., 2016) and many communities within the U.S. prohibit outdoor clotheslines (Geoghegan, 2010). Thus, a lack of structures on which to hang clothing is a major barrier to this behaviour. To overcome this barrier in the current project, hang drying racks were subsidized by ERC programme funds and offered to residents who expressed an interest in using one.

Washing in cold water. Some ERC clients reported staunch resistance to washing in cold water during interviews, however, previous interventions have shown that cold water washing is a malleable behaviour (Frantz et al., 2016). In the present study, cold water washing was targeted with materials developed and tested by the Urban Sustainability Directors Network in Asheville, NC; Berkeley, CA; and Tucson, AZ, with all three communities showing increases in cold water washing. The materials conveyed monetary savings and gave recommendations for a variety of cold water detergents that received positive reviews from consumer organizations. These recommendations were intended to address participants' skepticism that cold water washing

is as effective as washing in hot water In addition, client handouts included normative influence, in the form of testimonials, which has been shown to be effective in behaviour change efforts (e.g., Jaeger & Schultz, 2017). The materials did not, however, address the benefit of extended clothes life which emerged in the home interviews.

Heating Behaviours. Based on impact, penetration and probability, using window coverings was identified as a high priority behaviour whereas temperature 'setbacks,' using clothing and blankets to control comfort and closing windows were mid-priority.

Adjusting Window coverings. Interviews with staff revealed that strategic use of window coverings was a behaviour that some staff (28.57%) were already promoting. However, in-home interviews indicated a low penetration for this behaviour. Given that the behaviour was already being promoted, but not adopted, the team decided to provide clients and staff with the specific knowledge needed to execute the behaviour. Informational campaigns are not successful in persuading individuals to change behaviour (Abrahamse et al, 2005), but they can be effective when the audience has a high level of willingness.

Closing windows was more common than adjusting window coverings, but still endorsed in fewer than half of the in-home interviews, making it a mid-priority behaviour. Similarly, during in-home interviews a majority of participants reported ***grabbing a blanket*** (70%) or ***putting on warmer clothing*** (60%) when they are cold. Consequently, these behaviours were included in heating tips given to clients but were not a primary focus of the intervention.

Temperature setbacks refer to the practice of lowering heating setpoints when residents are sleeping and/or leaving home. Temperature setbacks can be achieved manually or automatically (with a programmable thermostat). Past literature recommended setbacks of 5°-10 °F for significant savings (Ehrhardt-Martinez, 2010; Reaves et al., 2016; Urban & Gomez, 2012), with the caveat that recommending too aggressive a change can backfire by causing residents to override the system with a higher temperature. Thus, in the current project, heating tips given to ERC clients included a recommendation and projected savings to be achieved by setting back thermostats by 5°F from their default (i.e., at-home and awake) temperature setpoint. The idea of setbacks assumes that residents will not only turn down the temperature of their homes when they are leaving or going to sleep but also that they will make their homes warmer when they return home or wake up. Thus, the energy savings that can be achieved with setbacks will vary depending upon the temperature adjustments residents make to restore comfort. Kempton (1986) estimates that between one-quarter and one-half of the U.S. population holds a valve theory of heating. Individuals who endorse a valve theory of heating believe that the higher one sets the temperature, the more 'power the system puts out to generate heat' (Kempton (1986; p. 81). Recordings of temperature fluctuations in these residents' homes show that they make larger and more frequent adjustments to their thermostat setpoints. In order to address the informational barrier underlying the valve theory of heating, the ERC programme involved presenting information, both written and oral, to clients explaining that larger increases in the setpoint will not heat their home faster.

Eliminating space heaters. Eliminating space heater usage was considered to be a low priority as a behavioural target based upon its penetration. However, since space heaters are both highly inefficient and dangerous (according to the U.S. Fire Administration, 2017, they are one of the top causes of house fires), the team decided to target space heater usage in the programme. Vivid, concrete examples were used to convey how much energy space heaters use (Gonzales, Aronson, & Costanzo, 1988).

DISCUSSION

New energy behaviour change programmes are introduced every day. They are being implemented by for-profit as well as non-profit organizations, by researchers and utilities. There are three key contributions that CBSM can make to these efforts. First, it is often the case that programme designers begin with the mindset, 'we need to increase/reduce X behaviour.' In contrast, CBSM encourages organizations to think about what they are trying to accomplish and outlines a rigorous process for deciding what behaviours to target in order to maximize the success of the programme. Second, programme elements are often chosen based on intuition. In CBSM, barriers and benefits for each behaviour are assessed and programme elements are selected to overcome barriers and leverage benefits. Third, evaluation is an essential component of the CBSM process. Often, this step is overlooked in programme implementation due to time and financial limitations. However, evaluation is necessary for establishing cost effective programming.

The case study described herein demonstrates how the steps in Community-Based Social Marketing can be used to create an effective behavioural engagement programme. Behaviours are selected based on a combination of penetration, probability and impact. Strategies, such as prompts, normative messages, removal of structural barriers, and information are matched to known barriers and benefits of the behaviours. After strategies have been selected, they are piloted and the programme is evaluated. The ERC case study programme was implemented beginning in February, 2017. Follow-up surveys have been received from 56 clients who received the programme and 38 who did not. Analyses of the survey responses are ongoing, however, preliminary results indicate that the programme was successful in changing several target behaviours and attitudes. Future energy consumption analyses are planned to compare clients who completed ERC's programme before and after the behavioural engagement programme was implemented.

The ERC case study included the development of materials for both clients and ERC staff. The programme includes a face-to-face component where ERC staff directly engage clients rather than merely leaving materials for the client to read in isolation. Consequently, organizational barriers were taken into consideration in selecting behaviours and strategies. For example, installation of programmable thermostats and education on how to use these thermostats was not included in the programme because of resistance from ERC staff. Moreover, ERC is a non-profit and as such has budget limits that affect how the programme could be designed. Allocating a specific staff member tasked with implementing and monitoring the behaviour change campaign would have been ideal, but it is not possible within ERC's funding model. By taking the organization into account, we were able to create a programme that is sustainable.

CONCLUSIONS

Research within social psychology predicts that incorporating behavioural programmes for residential energy use nationally could reduce U.S. household GHG emissions by 20% (Dietz, Gardner, Gilligan, Stern, & Vandenbergh, 2009). CBSM provides a framework for creating the types of tailored behavioural engagement programmes that can reduce energy use and corresponding GHG emissions.

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EXPLORING MONTE CARLO SIMULATION TECHNIQUE FOR CONSTRUCTION PROJECT RISK MANAGEMENT

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Key Words: Risk identification, Risk analysis, Simulation, Project management

Abstract

This paper aims to examine basic theories and principles of Monte Carlo Simulation (MCS) for analysing construction project risk management. The specific objectives are to review the origin of MSC, examine the basic principles and procedures of the technique for construction project risk management, and presents a case study to highlight its application in the construction management domain. Using literature review, findings indicate that although the origin of MCS in construction project management is unclear, its successive use in the analysis of risks has been widely acknowledged. Besides, MCS is discovered through this research to allow for sensitivity analysis and optimisation of real life situations without having to operate the real life system. However, findings reveal that the technique has obvious limitations which include among others high use of computer energy which makes it very expensive and time consuming to build simulation. It is recommended among others that project managers should avail themselves of the opportunity to acquire skill and technical experience to handle complex simulation problems in order to overcome the reluctance in using MCS.

INTRODUCTION

Construction project management represents series of complex activities with plenty of decision problems involving risks and uncertainty. According to PMI (2004), it is the process of planning, scheduling and controlling a construction project with a view towards achieving the desired quality standard, within a given time frame (schedule), at a given cost (budget) and in accordance with available technical and human resources. Given the obvious complexities and corresponding risks and uncertainties associated with resource allocation to project activities, project managers face difficult managerial tasks that only advanced modelling techniques such as simulation can ameliorate.

Simulation is a process of designing a model of a real system and conducting sensitivity analysis with the model with a view towards understanding the behaviour of the system (Chinbat and Takakuwa, 2009). It is a technique used by construction project managers to understand how systems such as the construction and project management processes behave in order to

optimise the system through various strategies in a virtual reality. Meanwhile, Monte Carlo Simulation (MCS), or probability simulation, is a technique used to understand the impact of risk and uncertainty in financial, project management, cost, and other forecasting models. Many researchers have demonstrated MCS as a viable technique for analysing risks in the construction management domain. For instance, Malini (1999) developed an MCS model for analysing risks inherent in Build, Operate and Transfer (BOT) type projects; Cagno and di Milano (2001) used MCS to analyse risks associated with completion time in construction projects; Ng et al. (2010) simulated the effects of risks on equity return for private, public partnership (PPP) projects using MCS; while recently Meins and Sager (2015) identified the relative contribution of sustainability criteria to property value risk using MCS.

Given the background above, this paper aims to examine the underlying theories and principles in the use of MCS. Specifically, the paper (1) discusses the origin of MSC, then (2) examines the basic principles and procedures of the technique for construction project risk management, and (3) presents a case study to highlight its application in the construction management domain, before finally discussing some challenges facing the use of MCS in real life situations in construction project management.

ORIGIN OF MONTE CARLO SIMULATION (MCS)

The Monte Carlo simulation includes any technique of statistical sampling employed to approximate solutions to quantitative problems (Monte Carlo Method, 2005). The first major variant of Monte Carlo simulation, also known as Monte Carlo method was initiated by an Italian scientist called Enrico Fermi while performing some experiments to understudy the concept of neutron diffusion. Unfortunately, none of his major discoveries were published. However the modern version of MCS was invented by a Polish-American mathematician, Stanislaw Ulam in the late 1940s while solving certain types of differential equation using probabilistic methods based on the initial layout of cards. After several unsuccessful attempts, he wondered whether a more practical method other than "abstract thinking" might not be to lay it out say one hundred times and simply observe and count the number of successful plays (Eckhardt, 1987). With the thought of new generation of fast computers now available, he made efforts to investigate the challenges of neutron diffusion and other questions begging for answers in mathematical physics, and more generally how to change processes described by certain differential equations into an equivalent form interpretable as a succession of random operations. He then joined hands with John Von Neumann to develop algorithms for sampling and rejection sampling. The two scientists were among several others who were working in the Los Alamos National Laboratory on how to develop the first nuclear reactor in a project called the Manhattan project which produced the first atomic bomb using in the Second World War (Monte Carlo Method, 2005). Because of the sensitive and secretive nature of the Manhattan project, a coded name was needed to protect its identity. Monte Carlo was therefore suggested by Nicholas Metropolis, an American physicist who jointly worked with

Von Neumann and Ulam, in reference to the famous Monte Carlo casino located in the Spanish city of Monaco.

Since its first invention, MCS has become popular in the fields of physics, physical chemistry and operation research while several versions of the technique have been developed by scientists to solve real life scenarios. For instance, the theory of more sophisticated mean field type particle Monte Carlo methods started in the mid-1960s with the work of Henry McKean Jr. on markov interpretations of a class of non-linear parabolic partial differential equation arising in fluid mechanics (McKean, 1967). Besides, another variant of Monte Carlo methods by Enrico Fermi and Robert Richtmyer came into existence in 1948. It is called Quantum Monte Carlo methods and was developed to interpret neutron-chain reactions (Enrique and Richtmyer, 1948); while Sequential Monte Carlo used for advanced signal processing and Bayesian statistical inference was invented in 1993 by a group of scientists led by Gordon N.J Gordon et al. (1993).

Although the origin of MCS in construction project management is unclear, its successive use in the analysis of risks has been widely acknowledged. According to Project Management Institute, PMI (2004), project managers are increasingly using it to quantify risks particularly with regards to project schedule and budget to justify schedule and budget reserves. This is with a view towards managing uncertainties that could adversely jeopardise project delivery outcomes.

PRINCIPLES AND PROCEDURES OF MCS FOR RISK MANAGEMENT

Monte Carlo simulation is a computerized mathematical technique that relies on repeated random sampling to generate results that best fits a particular problem (Raychaudhuri, 2008). It is argued that many of the most useful techniques use deterministic, pseudorandom sequences in order to allow for re-run of simulations. However, this trend is not indefinite as Sawilowsky (2003) has suggested the qualities of a good MCS as:

1. the (pseudo-random) number generator has certain characteristics (e.g. a long "period" before the sequence repeats)
2. the (pseudo-random) number generator produces values that pass tests for randomness
3. there are enough samples to ensure accurate results
4. the proper sampling technique is used
5. the algorithm used is valid for what is being modelled
6. it simulates the phenomenon in question.

Generally, Monte Carlo methods vary, but tend to follow a particular pattern:

1. Define a domain of possible inputs.
2. Generate inputs randomly from a probability distribution over the domain.
3. Perform a deterministic computation on the inputs.

4. Aggregate the results.

According to Raychaudhuri (2008), every Monte Carlo simulation starts with defining a deterministic domain of possible scenarios which closely resembles the real scenario. In the deterministic model, the most likely value (or the base case) of the input parameters are used by applying mathematical relationships which use the values of the input variables, and transform them into the desired output. This is then followed by adding the risk components to the model. Finally statistical analysis is performed on the output values derived from simulation and provides statistical confidence for the decisions likely to be taken after running the simulation.

Within the context of construction project risk management, Nemuth (2008) developed a two stage procedure for risk assessment in estimation and tender process using MCS. The first stage involves identification and analysis of project risks as well as identification of knock-outcriteria. The second stage involves four processes namely; (1) input the threshold risk values, (2) run the simulation and interpret result, (3) conduct sensitivity analysis, and (4) conduct evaluation to identify the project risk that has the highest influence. Wittwer (2004) developed five steps involved in MCS corresponding to uncertainty propagation in construction project risk management. They are:

1. Create a parametric model $y = f(x_1 \ldots\ldots x_n)$
2. Generate a set of random inputs $x_{i1} \ldots\ldots\ldots\ldots x_{iq}$
3. Evaluate the model and store the results as y_i
4. Repeat steps 2and 3 for i = 1……n
5. Analyse the results using histograms, summary statistics, confidence intervals etc.,

Figure 3 is a typical framework model for conducting MCS in construction project risk management. It is developed from the works of Raychaudhuri (2008), Nemuth (2008), Du and Li (2008), Ng et al. (2010) and Yazid et al. (2010). Eight (8) phases are integrated using a flowchart methodology to depict the procedural stages involved in MCS for project risk management. They are:

1. The first phase is the identification and classification of all project risks. This involves identifying and classifying all the risks that pose a threat to the project, service, or contract. In other words, the underlying distributions which govern the input variables are identified since the risks originate from the stochastic nature of the input variables. This step needs historical data for the input variables. The source and consequences of risks occurring will of course differ from party to party, with the contractor's perceived risks being quite different from those of the client organisation.

The objective of risk analysis is to determine what the impact or consequences would be of a risk event occurring. In other words, likelihood of occurrence as well as severity of occurrence are determined to develop the clearly defined impact or consequence of the risk identified.

2. The second phase involves generating some random numbers to determine the risk factors affecting the project variables such as cost and schedule. Once the underlying distributions have been identified for the input variables, a set of random numbers (also called random variates or random samples) are generated from these distributions.

3. This process is then repeated by generating more sets of random numbers in the **third phase** for say i=1…..n times, one for each input distribution, and collecting different sets of possible output values. This is the deterministic computation stage which is the core component of MCS. The initial result of MCS is a probability distribution. An example is shown in figure 1 in which the lower an upper risk limits are 4.96% and 8.26%. It means that with a probability of 95% confidence level, project risk will not fall below 4.96% while it will not be more than 8.26%.

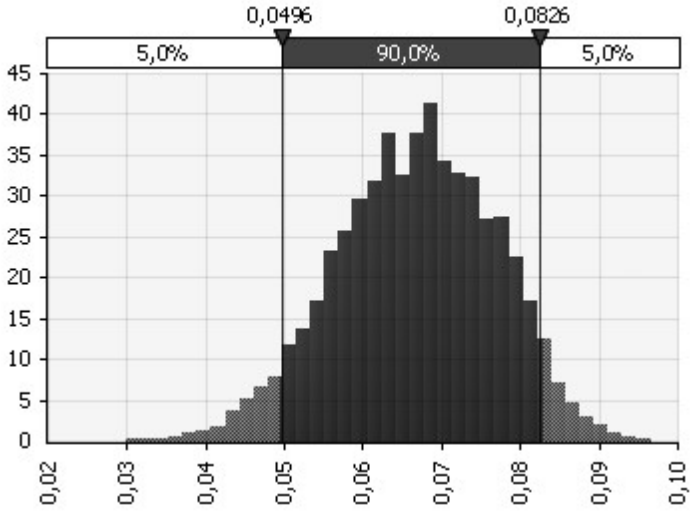

Figure 1: MCS Probability density result (Adapted from Nemuth (2008))

4. The fourth stage is the sensitivity analysis. This involves running additional MCSs where however input values are varied in the range of 5 to 10%. The results of the sensitivity analysis will indicate the influence of alteration made to every individual input value.

5. The fifth stage involves carrying out further evaluation using regression analysis to investigate and determine the underlying relationships between the risk variables with a view towards establishing how they influence project variables and ultimately project delivery outcomes. An example is shown in figure 2 and adapted from the work of Nemuth (2008).

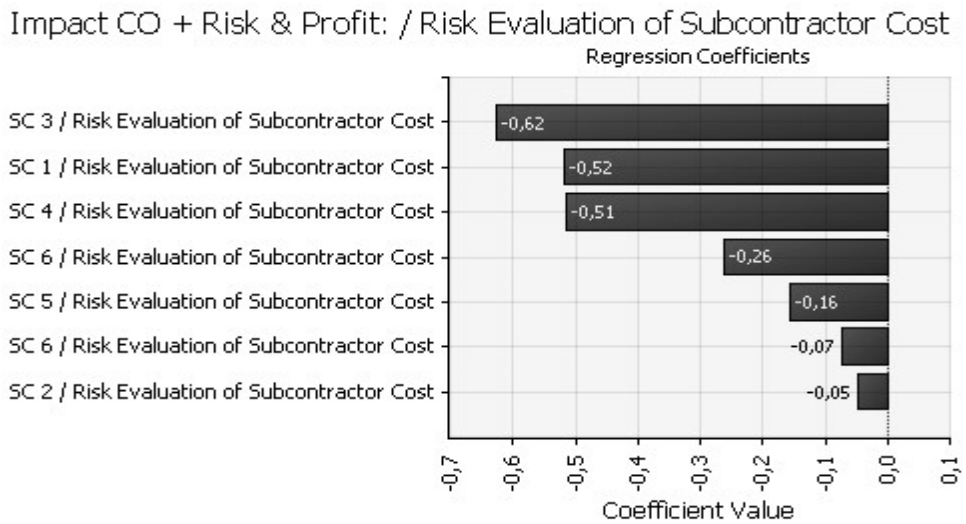

Figure 2: MCS Risk Evaluation result (Adapted from Nemuth (2008))

It shows the result of an evaluation procedure in which subcontractors 3, 1 and 4 with regression coefficients of -0.62, -0.52, and -0.51 respectively were found to have the highest significant loadings on project risk and profit. The implication is that these 3 subcontractors would have to be specially monitored during project execution.

6. The sixth phase is the extraction of simulation results for analysis. This could be done with the help of histograms, summary statistics, bar charts and confidence intervals.
7. Phases seven and eight include conclusion of the simulation and printing of results for report purposes. Rational decision can then be confidently taken based on the outcome of the MCS.

Therefore, a quality MCS done using the 8 principles outlined above with particular reference to probabilistic modelling to cost estimates for example could help to identify:

1. The mathematical probability that a cost overrun would occur;
2. The amount of financial exposure (how much it can get);
3. Risks and opportunities in order of bottom line importance; and
4. The contingency required for a given level of confidence (Wideman, 1992).

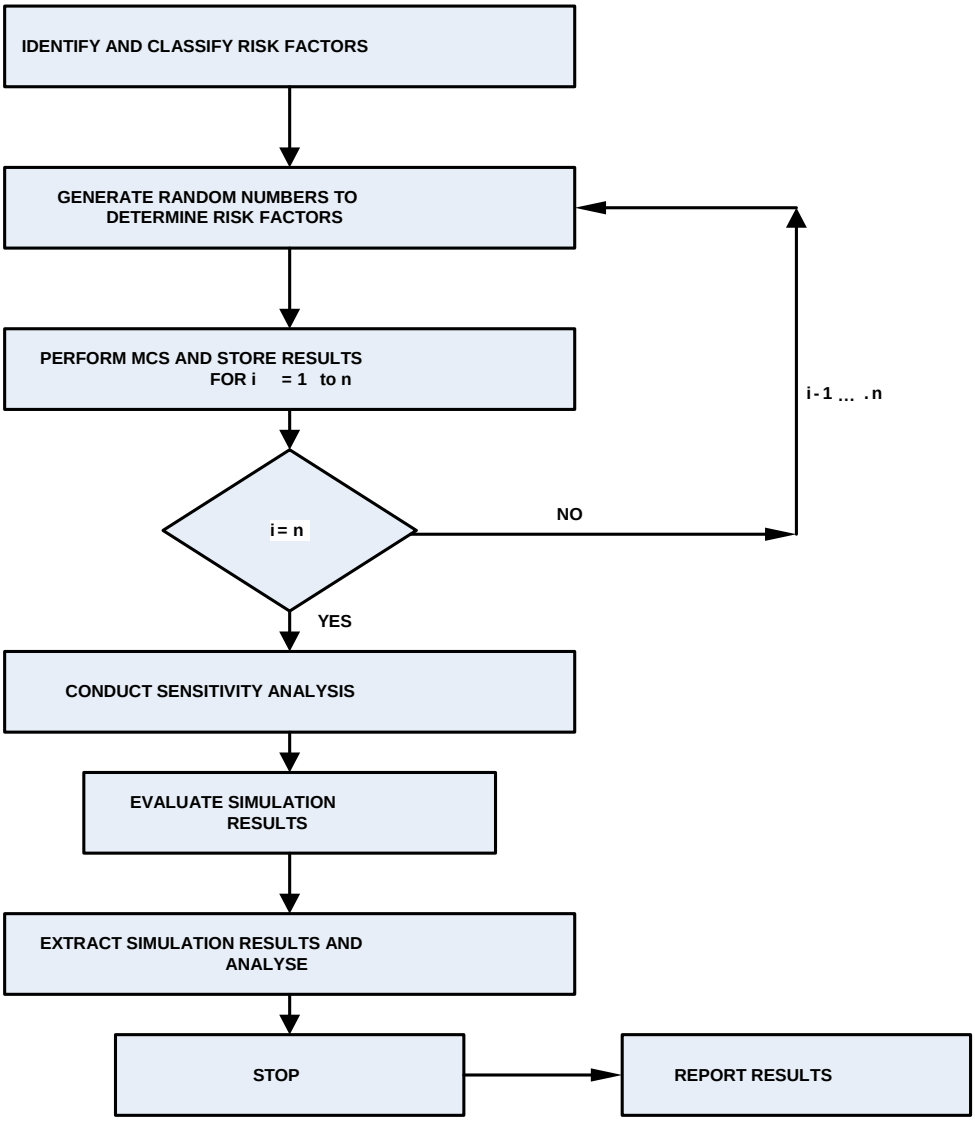

Figure 3: Framework for conducting MCS in construction project risk management

CASE STUDY ON THE USE OF MCS IN PROJECT RISK MANAGEMENT

In order to demonstrate the application of MCS in real life situations, a case study example found in the literature is hereby presented.

Ng et al. (2010) used MCS to establish the probability distribution of two indicators (namely amount of equity and return on equity) under the influence of risks for a concession-based public-private partnership (PPP) project. They did this by applying procedural steps discussed in section 2 of this book chapter. According to the authors, a road project was planned to be delivered by concession-based PPP with the basic parameters as follows:

i. The concession period is 15 years, and it will take five years to construct.

ii. The construction cost is $120,000,000, and which will be apportioned annually in 10 per cent, 20 per cent, 30 per cent, 20 per cent, and 20 per cent components during the five-year construction period, respectively.

iii. The debt capital principal is $100,000,000 from a 15-year bank loan with a 10 per cent interest rate, and this would be drawn in the five-year construction period according to the above profile of 10 per cent, 20 per cent, 30 per cent, 20 per cent, and 20 per cent. The residual cost is fulfilled by the equity with a finance cost of 15 per cent.

iv. The weighted average cost of capital (WACC) (i.e. discount rate) is 12 per cent and the risk-adjusted WACC for calculating the project value is 13.2 per cent.

v. The estimated traffic volume and proposed toll regime were computed while there would be a toll increase at a rate of 20 per cent every three years. The per annum operation and maintenance cost is 15 per cent of the per annum operational revenue.

Based on the initial data, net present value analysis (NPV) analysis was first conducted. On this basis, the NPV was computed to be $25,197,100 with a payback period (PBP) of 12.89 years, while the IRR is 15.20 per cent. This analysis shows that the proposed scheme is acceptable as NPV>0, and the franchisee can recover his investment before the end of concession period (i.e. PBP >15). Besides, the internal rate of return (IRR) of total capital is more preferable than the WACC of the franchisee (i.e. IRR > 12 per cent).

Before analysis and simulation, the authors assumed that the predominant risk factors that the franchisee would bear in this project are inflation rate, traffic flow and operation cost:

i. *Inflation rate* – The year-to-year rate of change follows a normal distribution with mean and standard deviation equal to 1 per cent and 0.5 per cent respectively. ii. *Traffic flow* – The estimated average annual traffic volume would follow a normal distribution with standard deviation equal to 20 per cent of the first year's traffic volume.

iii. *Operation cost* – The rates of change in annual operation and maintenance cost follow a uniform distribution at an interval of 0.13 and 0.17.

The simulation was run for 1,000 times and some statistical observations were drawn from the simulated distributions. For instance, the mean and standard deviation of equity net present value (ENPV) were found to be $3,060,200 and $2,900,600, respectively, and the cumulative probability of this indicator being less than zero is 0.1430 meaning that the confidence level of the ENPV being greater than zero is 0.8570 (i.e. 1-0.1430). According to the authors, the simulation has now indicated that the equity investors can recover their investment and gain a return rate of more than 15 per cent with a probability of 0.8570. The study also reported that the simulated distribution of RRE, the cumulative probability that the equity return is less than the financing cost of equity (i.e. 15 per cent) is also 0.1430. Besides, the confidence level for the equity return being larger than 20 per cent is around 0.5.

The case study was able to show that by referring to the cumulative probability of the simulated distributions for these two indicators, the confidence level with which the equity investors can recover their investment and gain a desired return rate can be established. Therefore based upon the risk attitude of the investor, decision-makers can then decide whether the scheme should be pursued or not. Besides, it has also reinforced one of the strengths of MCS in that the model can help decision-makers to adjust their investment strategies, for example by increasing or reducing the amount of debt or changing the investment proportion during the construction period, etc. By altering the model inputs, various what-if scenarios can be generated before a proposal is submitted.

LIMITATIONS OF MCS

Despite the huge popularity of MCS, some drawbacks still exist. First, MCS requires high use of computer energy which makes it very expensive and time consuming to build simulation. Besides, Kwak and Ingall (2009) argues that lack of easy-to-use software tools to run very complex simulations involving project schedule and cost is also a major drawback. However recent improvements in software technology have made these concerns virtually obsolete. Secondly, it has been argued that MCS can be easily misused by stretching it beyond the limit of credibility. This problem is particularly apparent when using patented simulation packages whose ease of use and lack of familiarity with underlying assumptions and restrictions make them vulnerable to abuse. Thirdly, MCS though an extremely powerful tool may reflect real life situations inaccurately or inappropriately. For instance, if project duration distributions used for simulations are incorrect or inadequate, the simulation resulting from that would be far from being credible. This is why Kwak and Ingall (2009) suggested that prior experience and detailed data from previous projects of same type are both useful in mitigating the estimate uncertainty. Finally, MCS usually requires several runs at given input values. This is in contrast with analytical solutions that provide exact values.

CONCLUSION

The paper examined the principles and uses of MCS for construction project risk management and specifically explored the origin as well as the basic procedural steps for running MCS, and thereafter presented a case study research carried out by a group of researchers to demonstrate how it works.

MCS is found to be certainly a project manager's delight for analysing project risks and often times the only type of model possible for complex real life situation as is reminiscent in the construction industry. Besides, MCS is discovered through this research to allow for sensitivity analysis and optimisation of real life situations without having to operate the real life system. Nevertheless, MCS is still far from being a perfect tool in current project management circles due to some perceived drawbacks and inhibitors discussed in the paper. It is recommended among others that project managers should avail themselves of the opportunity to acquire skill

and technical experience to handle complex simulation problems in order to overcome the reluctance in using MCS.

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REVIEW OF STUDIES ON RELATIONSHIP MANAGEMENT IN CONSTRUCTION PROJECTS

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Keywords: Relationship management, construction projects, project management, critical review

Abstract

Relationship management, as a "soft" management approach, has a crucial meaning for the success of construction projects. Researchers have gradually realised the significance of relationship management in construction projects since the second half of the 1990s. There appears to be lack of a systematic literature review on relationship management in construction projects. To bridge the gap, this paper analyses the previous research efforts of relationship management in construction projects by critically reviewing the retrieved papers published from 1994 to 2017. Four research topics relating to this field are determined, including (1) different perspectives of exploring relationship management; (2) key influencing factors of relationship management; (3) impacts of relationship management on construction project performance; and (4) characteristics of relationship management, especially in large construction projects. The paper provides insights into relationship management in construction projects with complex and dynamic nature. It is found that the researchers have begun to utilise social network analysis (SNA) to deal with the complexity of relationship management. Besides the dynamics of relationship management deserves efforts in the future research.

INTRODUCTION

Construction industry is increasingly project-based (Meng & Boyd, 2017). However, construction projects are likely to be beset with performance paradox (Flyvbjerg et al., 2003), including time delays, cost overruns, quality defects, safety incidents, as well as insufficient outcomes (Chan et al., 2015; Lo et al., 2006). It has been found that lack of collaborative relationships among project stakeholders is a critical reason to these performance problems of construction projects (Cook & Hancher, 1990; Eriksson & Laan, 2007). Chan et al. (2015) believed that good relationships among construction project parties plays a crucial role in project performance and project success. Relationship management, as a "soft" management approach, centres on the significance of people in project processes and attempts to avoid the poor performance by coordinating and managing relationships among project stakeholders. Being aware of the benefits of relationship management, increasing attention has been received from construction practitioners and researchers.

Although the research on relationship management in construction projects is still in initial stages (Yang & Shen, 2014), it is necessary to undertake a systematic examination of existing publications in this field. Literature review is considered as a useful methodology to obtain an in-depth understanding and overall picture of a research topic. Researchers could identify the existing body of knowledge and generate inspirations for future research by a high-quality literature review (Mok et al., 2015). Despite the importance of a literature view, there is no such work regarding relationship management in construction projects currently. This research presents a critical review of the literature on relationship management in construction projects, aiming to investigate the state of the art and and identify future research trends.

OVERVIEW OF RELATIONSHIP AND RELATIONSHIP MANAGEMENT

Relationship is defined by Oxford English Dictionary as the way in which two or more people or groups feel about and behave towards each other (Meng & Boyd, 2017). Keast & Hampson (2007) mentioned that synergistic outcomes which are impossible in single agency or by contracts can be come true by relationships. In construction, relationships mainly include three forms, namely traditionally adversarial, short-term collaborative relationship and long-term collaborative relationship (Meng, 2012). It has been found that collaborative and harmonious relationships are becoming more and more integral to good performance and project success (Bourne & Walker, 2008; Meng, 2012; Zou et al., 2014). Conversely, adversarial and deteriorated relationships are likely to cause poor performance and project failure (Meng, 2012). Therefore, a major shift is required from traditional adversarial relationships to collaborative relationships in construction (Egan, 2002). The development of relationships may be varied by diverse impact factors (Smyth & Edkins, 2007; Jiang, Henneberg & Naudé, 2011; Meng, 2012; Zou et al., 2014). Relationship management can achieve good collaborative relationship during project period by control and adjust diverse impact factors.

Relationship management is not an entirely new concept, it has attracted wide attention since the second half of the 1990s (Wise, 2008). However, the research on relationship management in many industries is still in its infancy, especially in the construction industry (Yang & Shen, 2014). Relationship management has been defined diversely within different contexts. In the business environment, customer relationship management is highlighted and defined as “a customer-focused business strategy that dynamically integrates sales, marketing and customer care service in order to create and add value for the company and its customers” (Chalmeta, 2006). As for relationship management in the project environment, it has been described by Bourne and Walker (2008) as the way that requires a project manager and project team to build and develop relationships with the suitable stakeholders at the appropriated time. Zou et al. (2014) defined relationship management in the context of Public-Private-Partnership (PPP) as a series of integrated strategies and processes of cooperation with selected partners and project stakeholders, to build superior value for PPP projects via sustainable development in relationships. Although the definitions of relationship management are slightly different, it is widely recognised that relationship management can generate economic, societal, and political gains for both organisations and publics (Ledingham, 2003). It means that, if

relationships are managed properly, both organisations and their stakeholders can benefit from the relationships. Therefore, relationship management, as a soft management approach, can be considered as a focus of next generation of project management in the construction industry (Davis & Pharro, 2003; Meng, 2012; Meng & Boyd, 2017).

METHODOLOGY

Although the research of relationship management is in its infancy, there are amounts of papers published linking to relationship management in construction projects. Tsai & Wen (2005) indicated that a methodical analysis of publications is essential to fully review and analyse the findings of previous studies in a particular topic or research area. It is necessary to establish a proper research framework to conduct the literature review of relationship management in construction projects effectively. The research framework can be shown in Figure 1, including the following five steps:

1) Selection of databases. In order to achieve a comprehensive search on the subject area, two databases, Scopus and Web of Science (WoS) are selected to obtain the initially retrieved papers.

2) Selection of time span. Although the relationship management has been drawn wide attention since the second half of the 1990s, there are still some relevant literatures before that time. Threrfore, a comprehensive search does not prescribe a limit to the time span of papers (Wise, 2008).

3) Search with keywords about the research topic. Two search rules used in the study are as follows:

a) ("relationship management" OR "relational contracting" OR "relationship marketing" OR "relationship governance") AND ("construction projects"); and
b) ("partnering" OR "trust") AND ("management" OR "managing" OR "managerial" OR "manage") AND ("construction projects").

Through the search with these two rules by Scopus and WoS engines, a total of 692 papers are obtained.

4) Visual examination. 692 is a large number in terms of the papers for a literature review. On the other hand, some of these papers are less relevant to the research topic. Therefore some papers are filtered out by visual examination. After visual examination, 76 papers are left for the literature review.

5) Classification. The 76 remaining papers are reviewed carefully and thoroughly. They can be classified into five categories based on their contents, namely different perspectives of exploring relationship management, key influencing factors of relationship management, impacts of relationship management on project performance, characteristics of relationship

management in construction projects, especially in large construction projects. The classification of the relevant papers will support for further content analysis.

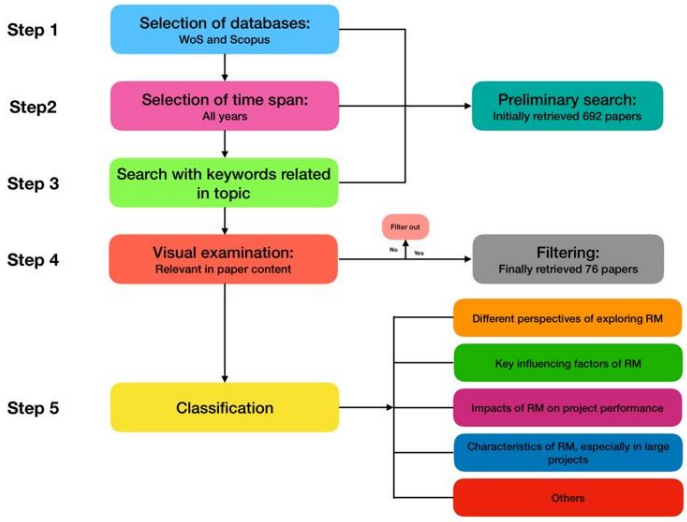

Figure 1Methodology framework of the research

ANALYSIS RESULTS

The literature analysis will mainly focus on quantities of papers, research sources (the world class journals or the international conferences), and research origins (countries where the authors of the analysed papers are situated in), thus providing detailed results of 76 analysed papers.

Number of Papers

During the period from 1994 to 2017, the quantities of analysed papers are growing relatively over the years and reached the peak of 8, 7, 6 and 6 in the years of 2007, 2017, 2008 and 2015 respectively (see Figure 2). The quantities of relevant papers in last decades are dramatically increasing, which indicates the growing attention of academia to the subject. It is an appropriate time to produce a systematic review of existing literatures.

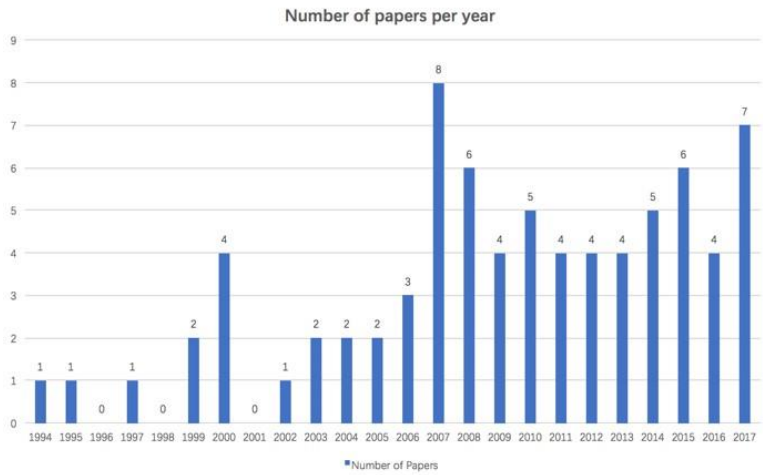

Figure 2 Numbers of papers per year

Research Sources

Papers relevant to relationship management in construction projects in the following 3 leading journals are used: International Journal of Project Management (IJPM), Journal of Construction Engineering and Management (JCEM), Construction Management and Economics (CME). Over the period from 1994 to 2017, IJPM published the largest number of papers related to the subject, namely 14 papers. IJPM is followed by JCEM and CME, both with 4 papers.

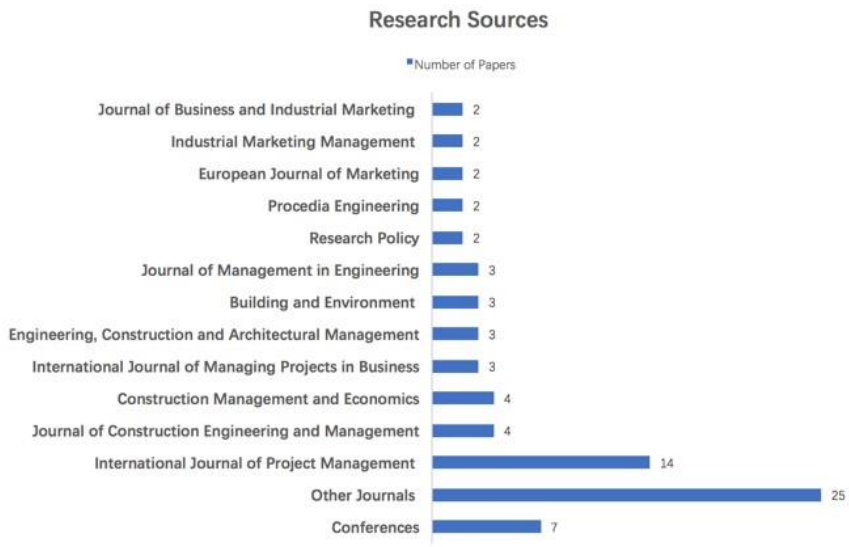

Figure 3 Research sources

Research origins

In order to assess the research contribution by different countries, the analysis of research origins is conducted. The origins of papers are identified based upon authors' situated countries. According to Table 1, the United Kingdom stands out at the top of the list with 22 papers. China Hong Kong appears in second place with 11 papers, followed by the United States and Australia, with 8 papers and 7 papers respectively.

Country	Number of Papers	Percentage
UK	22	28.9%
China, HK	11	14.5%
USA	8	10.5%
Australia	7	9.2%
Finland	4	5.3%
China	3	3.9%
Germany	3	3.9%
Norway	3	3.9%
France	2	2.6%
South Africa	2	2.6%
New Zealand	2	2.6%
Spain	1	1.3%
Singapore	1	1.3%
Poland	1	1.3%
Netherlands	1	1.3%
Ireland	1	1.3%
Denmark	1	1.3%
Greece	1	1.3%
Canada	1	1.3%
Belgium	1	1.3%
Total	**76**	**100.0%**

Table 1 Authors situated countries

CRITICAL REVIEW OF PREVIOUS STUDIES

Different perspectives of exploring relationship management

As mentioned above, the research on relationship management is still at initial stages. There are insufficient previous studies more directly focused on relationship management. However, many scholars have provided insights from different points of view into relationship management, like relationship marketing and relational contracting.

Relationship management has stemmed from relationship marketing (Gummesson, 2001). Relationship marketing can be considered as an approach to establish strong bonds with a firm's stakeholders, especially customers, through encouraging efficient communication and facilitating mutual trust, commitment, long-term engagement, as well as creating exchanges of mutually beneficial value (Christopher et al., 2002; Grönroos, 2007; Gummesson, 2008). Some studies have been conducted to explore relationship marketing. For example, Payne et

al. (2005) formulated the “six markets” stakeholder model, aiming to highlight the significance of relationships between a firm and all stakeholder groups in different markets, including customers, referrals, influencers, recruitment, suppliers, and internal markets. On the other hand,
Gummesson (2008) identified thirty relationships (30R), classified under four headings:

1) classic market relationships (dyadic);

2) special market relationship (e.g. alliances);

3) mega market relationships (supra-influencers/stakeholders);

4) nano market relationships (internal).

Each type of relationship in a market requires urgently proactive management (Smyth & Fitch, 2009). Consequently, relationship marketing began to transform into a management approach. As a result, relationship management was developed (Grönroos, 2007).

There is a conceptual distinction between relational contracting and relationship management (Smyth & Fitch, 2009). As a branch of transaction cost theory, relational contracting is a top-down approach to give a reactive response in behaviour (Smyth & Fitch, 2009). Once the external market changes, the internal adjustments are required to behaviour and customer-supplier interface (Smyth & Edkins, 2007). Relationship management as a competency for incurring more cooperative forms of behaviour is a bottom-up approach to solicit behavioural changes proactively in aggregate behaviour (Smyth & Fitch, 2009). Proactive change and development of relationships within the firm and at the interface with stakeholders will be required if set of changes induce internally. What’s more, it is likely that such internal change has an external impact upon the market (Smyth & Edkins, 2007). Smyth & Fitch (2009) summarised the exact differences between relational contracting and relationship management (Table 2).

Relational Contracting	Relationship Management
Market driven	Organizationally driven
Structural change to induce behavioural change	Process changes to improve performance and induce structural change
Governance through client procurement requirements	Aggregated behaviour through contractor strategic choice
Top down	Bottom up
Reactive response	Proactive response
Project commitment	Corporate commitment across projects
Low investment	High investment

Table 2The differences between relational contracting and relationship management

Although relational contracting is distinct from relationship management (Smyth & Fitch, 2009), it is possible to transfer relational contracting to relationship management in practice if internal stakeholders are attempting to maintain continuous improvement over a programme of project (Anvuur and Kumaraswamy, 2008; Skitmore and Smyth, 2007).

Key influencing factors of relationship management

Smyth, Gustafsson & Ganskau (2010) mentioned trust has an important meaning to all relationships and it can be regarded as foundational in forming and maintaining relationships (Baier, 1994; Smyth, 2008). Many scholars study relationship management starting with trust. Therefore, it should be self-evidence that exploring key influencing factors of relationship management starts with trust. Scholars have identified and interpreted various factors which lead to building trust. the key factors influencing trust can be classified as four categories:

1) Long-time relationship;

2) Problem solving skill;

3) Partners' reputation & financial stability; and

4) Reasonable behaviour.

Spending time with people and working with them can be considered as a basis to build trust (Khalfan, McDermott & Swan, 2007). Kadefors (2004) agreed that building trust should be through repeated interactions overtime.

Problem solving skill can be deemed as a vital element for trust building (Wong et al., 2005). Social setting can be changed in unpredictable way and problems and disputes can arise as time goes on (Khalfan, McDermott & Swan, 2007). If a problem is settled with forbearance rather than blaming and a dispute is resolved with a satisfied way, it would lead to higher trust and satisfaction with relationships (Selnes, 1998).

Partners' reputation and financial stability can affect the level of trust (Wong & Cheung, 2004; Wong et al., 2005). Whether partners can be trusted depends on their reputation, explaining why many organisations consider their reputations as a vital intangible asset (Khalfan, McDermott & Swan, 2007). In terms of partners' financial stability, it is an essential element to develop trusting relationship (Khalfan, McDermott & Swan, 2007). According to Drexler & Larson (2000), partners with financial capacity are more reliable as the risks which they exploit loopholes in the contract or raise absurd claims would be reduced.

Reasonable behaviours consist of reliable working style, effective communication and information exchange. People tend to measure whether a partner deserves their trust or not through watching out a partner's punctuality, working fairly and professionally, efficiency and alignment of words and actions (Ling & Tran, 2012; Butler, 1991). Besides, effective communication and information exchange also have a positive impact on the trust level. Chan et al. (2004) stated that effective communication among partners can promote the development of trust, as it could maintain transparency, encourage joint problem solving, enhance adaptability, smooth information exchange and obtain better performance.

As above-mentioned, trust can be regarded as an antecedent of relationship development. A high level of trust can increase the confidence in the relationship (Ganesan, 1994). Some scholars have begun to conduct researches of relationship management since the research of trust came to maturity. The scholars found that in addition to above-mentioned influencing factors, there are other three factors influencing the establishment and management of relationship supplemented:

1) Mutual objectives;

2) Long-term commitment; and

3) No-blame & sharing culture.

The strategic objectives of each individual organisation can converge to form the mutual and consistent objectives of the alliance, thus binding all organisations together and promoting their relationship development (Chen & Chen, 2007). If individual parties tend to be dominated by their own objectives instead of mutual objectives which may be conflicting, adversarial relationships are likely to be occur (Love, Gunasekaran & Li, 1998).

Long-term commitment refers to the willingness of the involved parties to solve any unanticipated problems continuously (Bresnen & Marshall 2000; Cheng et al. 2000). Long-term commitment could be linked with the success of relationship development, as more committed parties are likely to give up opportunistic behaviour and make great efforts to balance the achievement of short-term objectives with that of longterm objectives (Mohr & Spekman, 1994).

Partners' culture also affects the establishment and development of a relationship. Creating the non-blame culture could provide an opportunity for joint working and problem solving, thus promoting relationship development (Meng, 2012). In terms the sharing culture, an organisation would like to share its own resources, including confidential information, special technology and useful experience, with other organisations shows their willingness of becoming vulnerable (Davis, 2008). Such resources are utilised to reinforce the competitiveness of the partnering relationship, but also facilitate the relationship success (Cheng et al., 2000).

Impact of relationship management on construction project performance / project success

Many studies have identified that project performance and project success can be measured by the iron triangle (time, cost and quality) (Meng, 2012). Chadwick & Rajagopal (1995) indicated that successful partnering could enable constant improvements in time, cost and quality of a project. Adopting partnering also could enhance the capability of the organisation to meet the client's requirements as well as increase client satisfaction (Black, Akintoye & Fitzgerald, 2000).

In Meng & Boyd (2017)'s study, they explore the effect of relationship management on project performance in terms of time, cost, quality and client satisfaction. Relationship management can be divided into internal relationship management (the relationship among different members in the same project organisation) and external organisation relationship management (the relationship among different project organisations) (Mazur & Pisarski, 2015). They found project performance in terms of cost, time and quality are more impacted by internal relationship management; whereas client satisfaction is more impacted by external relationship management.

Besides above-mentioned performances, safety performance and innovation and improvement are supplemented in Yeung and his colleagues's study. Some scholars demonstrated that relationship management has impact on safety performance and innovation and improvement. For example, Black, Akintoye & Fitzgerald (2000) believed safety performance can be improved by stakeholders working with a collaborative relationship. O'Toole & Donaldson (2000) considered relationship management can benefit to technology development and specialisation.

Characteristics of relationship management

Projects extremely rely on the participation, reactions and interactions of stakeholders, project environment characterised by complexity, dynamics and uncertainty easily become a breeding ground for adversarial relationships and defensive behaviour (Azim et al., 2010; Lau & Rowlinson, 2011). Rowley (1997) emphasised that stakeholders' relationships are not static, they are dynamic and changing constantly. The composition, attitudes and actions of stakeholders is changing over time in accordance with the dynamic project environment, which reflect the dynamic nature of the relationship management (Mok & Shen, 2016; Yang, Shen & Ho, 2009). The dynamic nature of stakeholder relationship in projects tends to add the complexity of managing stakeholder relationships (Dooms, Verbeke & Haezendonck, 2013). Bourne (2010) proposed that each stakeholder in projects are unique and the relationships among stakeholders reflect uniqueness and complexity. Therefore, relationship management in projects has complexity and uncertainty, and it cannot use simple formula to represent (Bourne, 2010).

Compared to small and medium construction projects, large construction projects involve numerous project stakeholders, conflicting interests, long-lasting impacts on social, economic and environmental aspects, thus dramatically increasing the complexity of project environment (Van Marrewijk et al., 2008; Terje Karlsen, Græe & Jensvold Massaoud, 2008; Hu et al., 2013). There are also more uncertain and dynamic circumstances along with the increasing size of projects (Yang & Shen, 2014). In large construction projects, stakeholders develop an extensive social network of interorganisational and intra-organisational relationships among themselves, they are connected directly or indirectly by various relationship networks instead of being isolated in vacuum (Mok & Shen, 2016; Terje Karlsen, Græe & Jensvold Massaoud, 2008). Compared to small and medium construction projects, relationship management plays a more vital role to support the success of large construction

projects (Meng & Boyd, 2017). High-quality project relationships tend to help to overcome the turbulence which is normally bound to arise during any large project (Chi et al., 2011).

CONCLUSION

Relationship management is the supervision and maintenance of relationship between different people and different organisations. It can be considered as a centre of modern theories of project management (Meng & Boyd, 2017), as it is of extreme significance to project performance and project success. Since the second half of 1990s, it has attracted increasing attention from both researchers and industry practitioners (Wise, 2008, Zou et al., 2014). Unfortunately, there seems not to be a systematic critical review related to relationship management in construction projects.

With the gradual growing number of relevant papers, it is a proper time to conduct a systematic critical review related to relationship management in construction projects.

This study undertakes a systematic overview of relationship management in construction projects by critically reviewing a total of 76 relevant papers published by academic journals and conferences from 1994 to 2017, attempting to provide an overall picture of previous researches and depict the research evolution of this field. In this review, the quantitative analysis of existing papers has been conducted in terms of the quantities of papers, research sources and research origins. It has been found that relationship management in construction projects arises more and more attention from the academia.

A content analysis of relevant papers shows that there are four key research topics in relation to relationship management in construction projects, including (1) different perspectives of exploring relationship management; (2) key influencing factors of relationship management; (3) impacts of relationship management on project performance; and (4) characteristics of relationship management, especially in large construction projects. Based on the review, there are many existing literatures exploring relationship management from various perspectives, but there is still a need to establish a firm and systematic management process to better achieve relationship management in construction projects, thus providing a useful guidance to the practitioners. In addition, early warning signs of relationship deterioration in construction projects should be identified so as to prevent relationship breakdown during the projects. Relationship management is characterised as complexity. The interactions and interrelationships among various projects stakeholders should be figured out by some available tools, like social network analysis. Dynamics of relationship management also deserves more efforts by scholars in the future research.

This critical review is of great value to the researchers as it not only provides a clear and comprehensive map of relationship management in construction projects, but also draws a blueprint for the future research in the field.

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A ROADMAP FOR C-SI SOLAR PANEL END-OF-LIFE TREATMENT

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Keywords: Solar Panels, Recycling, Silicon, Photovoltaic, End-of-Life Treatment

Abstract

As the installation of PV systems grows to promote a path for sustainable energy generation, solar panel recycling and end-of-life procedures have become areas of increasing concern. Given the post-2000s boom in PV installation, and the 25-30 year lifetime of a PV plant, the new industry created by this anticipated 20,000 tons of solar panel waste will be worth upwards of 112 million dollars by 2025 [7]. Building upon research that explores the limitations of Solar Panel Recycling (SPR) methodologies and economics, this paper will identify new factors for assessing the potential of this upcoming industry. These factors will support that SPR technology will be increasingly favorable than past research suggests. To begin forming a roadmap that outlines all necessary considerations for SPR infrastructure, a system dynamics approach has been utilized. A closed loop model was created to demonstrate industry potential based on technological limitations and economics for the U.S. and a small case study for the state of Maryland.

INTRODUCTION

The rapid expansion of the solar photovoltaic (PV) industry has resulted in solar playing a crucial role for the future of power generation systems. PV technology is considered to be a sustainable power generation process as it generates electricity directly from the sun and avoids fossil fuel consumption and greenhouse gas emission. Over the last decade, the technology has proven the ability to become a major generator for the world, with robust and continuous growth even during times of financial and economic crisis. Significant research and industry spending has gone into creating more efficient solar panel manufacturing, installation, and operations/maintenance procedures. An aspect of the technology that is often left out, however, is the End-ofLife Treatment (EoLT) of these solar power plants. SPR by nature can be used to reduce PV waste, utilize recycled raw materials, and create a closed-loop life cycle specifically for the U.S. solar industry. Up until now, there has not been a way of modelling factors in the SPR industry to draw conclusions on what a roadmap to designing it would require. However, through the SPR infrastructure model discussed in this paper, we are now able to explore how the industry will be affected by the following aspects: Number of installations per year in a given area, Rate of decommissioning for an average panel, Cost efficiency of recycling vs. landfill disposal rates, Previously developed SPR infrastructure, and Importance of SPR Awareness. It should be noted that within the context of this paper, “decommissioned” will refer to solar panels that are now ready to be disposed of per the end of their useful lifetime. To date, lack of awareness and concern about this issue is a result of very few panels having reached the point of decommissioning. Solar power plants have a

technical lifetime of 25-30 years, with installation of these plants occurring exponentially since the 2000s [15]. Currently, most PV modules that have reached their decommissioning date have either been defects during production, damaged during transportation and installation, or malfunctioned during their first year of operation. Based on the timeline established, and further research that will be provided below, the date when entire solar power plants will need to be decommissioned is quickly approaching. In order to insure that these panels are efficiently recycled and not disposed of in landfills, an infrastructure must be created in the U.S. to support a closed loop cycle for the solar industry that keeps the promise of sustainable power generation.

Before a closed loop SPR model can be created, the needs of this new and growing industry must be understood. The PV modules that will be the first to experience EoLT concerns in the next decade are those with crystalline silicon (c-Si) wafers. This is because c-Si panels were predominantly installed before the commercial validity of 2nd or 3rd generation solar technology, that utilize other chemical elements, was proven. To date, silicon wafer-based PV modules are still the most common type of solar cell manufactured in the world. Among the different technologies, c-Si PV technology still dominates the market, accounting for 85– 90% of the technology share [3]. Previous development of the small SPR industry that exists to date in the U.S., however, was designed to meet the needs of an entirely differently market. The push for the creation of these SPR processes originated from concerns about 3rd generation modules. These are solar panel modules that utilize materials such as cadmium, tellurium, lead, and selenium which are regulated and hazardous materials [4]. Concern for the effects of disposing these materials in municipal landfills put pressure on PV installers to have a structured end-of-life procedure determined before implementation, which has led to programs such as First Solar's CdTe-based recycling program, [5] and initial development of the SPR industry in the U.S. However, 3rd generation modules will not be the majority of solar panels requiring EoLT in the near future. As stated previously, c-Si modules are the bulk of the panels nearing their decommission date in the largest numbers. The outcome for this unmet market is an anticipated 20,000 tons of solar panel waste, worth upwards of 112 million dollars, by 2025 as reported by GM Insights.

Economics of SPR Industry

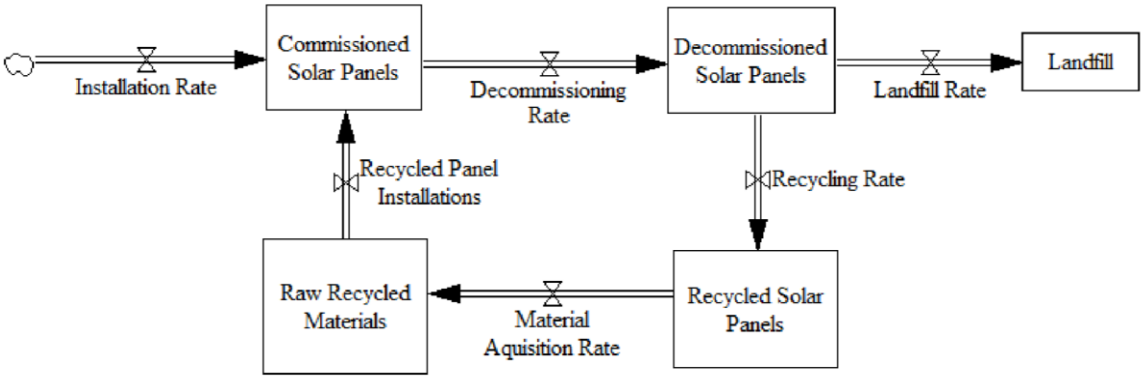
Based on past research, development of the SPR industry has already suggested strong economic validity. A study conducted by N.C. McDonald found the estimated total cost of collection and recycling of c-Si panels to be in the range of $0.08-0.11 / W. This is compared to the $23.96-23.99 per panel landfill disposal cost sited in the same study, meaning landfill disposal of a 300 watt solar panel would cost roughly $0.08 to decommission. At these comparable costs, it was determined at the time of the study, in 2010, that SPR was economically comparable with landfill rates. The average price to dispose of a ton of municipal solid waste in a U.S. landfill, however, has reported to be continuously rising. An IBISWorld Procurement Research study shows that from 2013 to 2016, the prices of landfill and solid waste collection services have increased at an estimated average rate of 1.7-2.9% per year. From 2016 to 2019, IBISWorld says it expects the prices of solid waste collection and disposal services to increase at a moderate annualized rate of 2.0%. The reasons behind this increase will not be explored in the scope of this paper, however, a parallel can easily be made to landfill

disposal costs overall. These factors suggest SPR may be more economically viable compared to landfill disposal with the passage of time based on cost efficiency.

An additional factor is the increasing cost of silicon and aluminum materials. On January 22, 2018 President Trump issued a 30% year-one tariff on imported solar cells and modules [9]. Tariffs are set to decline over a four-year period, with the first 2.5 gigawatts of imported cells excluded from the additional tariff in each of those four years, according to the U.S. Trade Representative. Many news outlets have speculated on the impact of this tariff, with a consensus in solar news reports being that the tariff will result in an increase in the cost of solar installations, as well as an in increase in domestically-made solar modules [10]. On March 8, 2018, President Trump also imposed a 10% tariff on aluminum imports, with the only exemptions being Canada and Mexico [11]. No connections have yet to be drawn between the aluminum tariff and its effects on the cost of purchasing and building solar panels. Solar panels, however, are 10.30% aluminum, which is the second largest component within the panel besides glass at 74.16% [12]. Being mindful of shifts in the solar panel political climate will likely prove beneficial when reconsidering the costs and significance of the SPR industry in the U.S.

Lastly, the increasing costs of silicon on a global scale will soon show favor of SPR. UMCO is a Japanese silicon wafer manufacturer estimated to provide two-thirds of the world's supply of silicon wafer. This silicon wafer is one of the raw materials used in semiconductor manufacturing and is utilized in everything from CPUs to GPUs and DRAM. SUMCO has confirmed the price of silicon wafer has jumped 20% this year alone, and it's set to continue rising substantially for the next few years at least. "We are also planning to increase the price of silicon wafer by 20% in 2018," said SUMCO CEO Hashimoto Mayuki. "Price of silicon wafer will continue to rise in 2019" [13]. As discussed in Muller et al., during the last decade the PV-industry has grown by more than 20% p.a. Today, about 15,000 tons / year of silicon are used by solar wafer manufacturers. The available silicon capacities of both microelectronic and PV industries are limited to 30,000 tons / year for the time being. His research suggests that the shortage of silicon supply could easily limit the growth of the PVindustry based on silicon availability and cost in the U.S. This again suggests the increasing validity of the SPR industry within a closed-loop system that utilizes cheaper materials already available on U.S. soil.

A Closed-Loop SPR Infrastructure Model

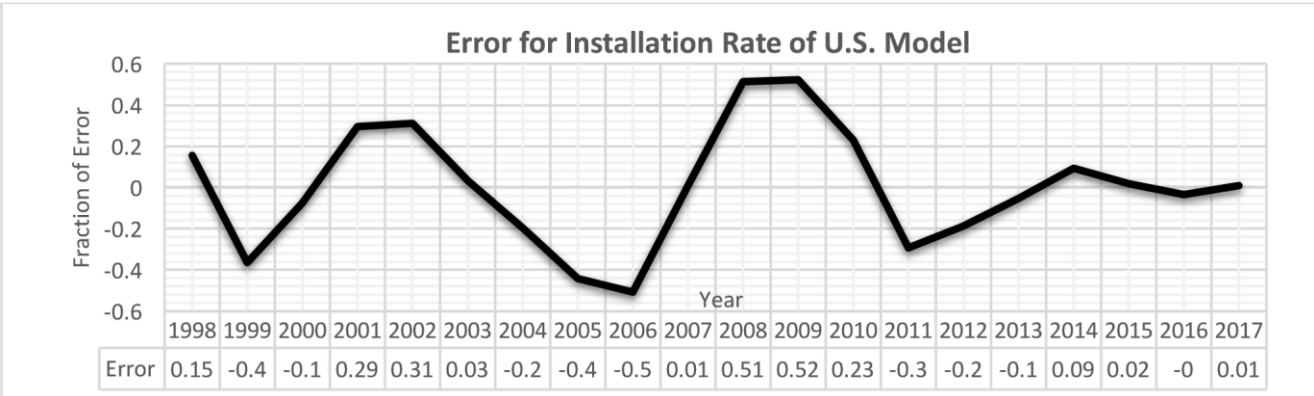


(1) SPR Infrastructure Feedback Loop

To map how the previously discussed aspects of the solar industry connect to development of a SPR infrastructure, the following model was developed using system dynamics software. The model is structured as follows. The input for the system is the number of installed c-Si solar panels in a region by year. This data was pulled from a report released by the U.S. Department of Energy in July 5th 2017. The report outlines, the kWhr/month of solar power generation in the U.S from 1998-2017. From this data, a function where the input is a time step, called "Time", starts at zero and models the number of installed panels per year in the U.S. Using the assumption that an average panel is 300 watts, with 5 average sun hours/day of exposure for an average of 30 days per month, one solar panel was determined to be roughly 45,000 kWhr/month. This made it simple to divide the function by this number and determine a function input for the number of panels per year installed from 2008 onwards, titled *Installation Rate* (2).

$$Panels/Year = -0.4303 \times Time^6 + 26.329 \times Time^5 - 568.35 \times Time^4 + 5597.2 \times Time^3 - 26034 \times Time^2 + 52239 \times Time - 21822 \quad (2)$$

The *Installation Rate* has an error due to the fact it is produced using a function versus specific data points per year. This error has been tracked in figure 3.



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Error	0.15	-0.4	-0.1	0.29	0.31	0.03	-0.2	-0.4	-0.5	0.01	0.51	0.52	0.23	-0.3	-0.2	-0.1	0.09	0.02	-0	0.01

(3) Error Calculation for Installation Rate function for the U.S. SPR Infrastructure Model

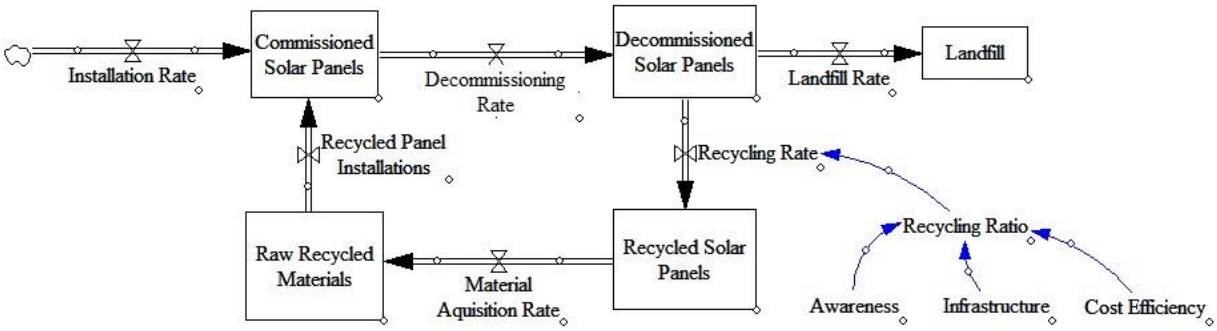
Although this error is relatively high initially, which we've been able to adjust using an adjustment ratio, a function is necessary instead of actual data values because it allows flexibility of the model for adjustments per region. After calibrating the model, the percentage of error decreases towards zero as time progresses, where it will effectively become more accurate for larger stretches of time modelled.

The next rate to consider is the *Decommissioned Rate*. This rate is based on how many panels need to be disposed of before the 25-30 year plant life concludes, and all the remaining panels are disposed of. It is based on the average number of panels that experience malfunctions or breakage based on what stage in their lifetime this has been shown to happen. Estimating this rate was based on a study done by Fthenakis, V.M. From it, the average delay of when commissioned solar panels need to be disposed of can be extrapolated. For the first year, 10% of the panels will need to be disposed of, whether this be to accidents, technological failures, etc. Then, from the 2nd-10th year 4.5% of panels will need disposal, and for the 10th-29th 0.05% respectively. At the 30th year it was assumed that all panels will be decommissioned based on

the U.S. standard. The function created for the *Decommissioning Rate* reflects all these delays. Lastly, the *Recycling Rate*, controlled by the *Recycling Ratio* shown in figure 5, was established by determining the three main factors that effect it, multiplied together:

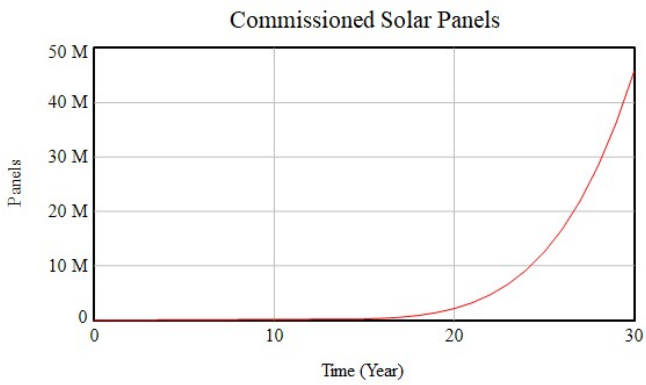
1. Awareness: The knowledge of SPR in the solar industry, as well as a strong public understanding of the technical and economic aspects of it.
2. Infrastructure: The amount of facilities in a region with the ability to recycling solar panels in a sustainable closed-loop process.
3. Cost Efficiency: How competitive SPR costs are with landfill disposal costs.

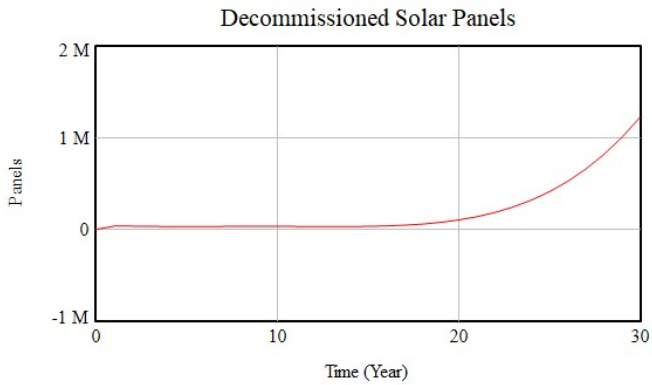
Awareness in this model is reflected using a 0 or 1 function. This assumes that awareness of the ability to recycle one's solar panels is the first step to recycling them. Without this, no panels get recycled, hence an overall *Recycling Rate* of 0. Per the definition of infrastructure above, infrastructure in the model is calculated based on the number of facilities in an area times the amount of panels that a SPR facility should be able recycle in a year. Each solar recycling facility should be able to handle a rated number of solar panels per year based on its capacity. Therefore this number of solar panels is multiplied by the number of facilities. Then, cost efficiency refers to the cost of solar recycling being competitive with landfill costs. This is also a 0 or 1 function. This will be assessed in terms of solar panel recycling legislation. Currently, there is only a 1-2 cent difference between the costs of solar panel recycling and landfill rates, as discussed more thoroughly above. Therefore, this function is controlled by the user of the model, and based on the arguments made previously, it was set to 1 for our model.



(5) SPR Infrastructure Feedback Loop with Recycling Ratio displayed

The subsequent stocks and flows in the model are determined by calculating how many raw materials can be recycled from a solar panel and how much raw material is needed to remake a new panel. It was determined that 1/0.015 of a ton of these raw materials can be used to make a new solar panel based on the average weight and recyclable material from a panel. This is also presuming reuse of 90% of the panel as demonstrated by PV Cycle [7]. These values are then used to complete a full lifecycle roadmap. The output of our model is shown in figures 6 and 7. For these graphs, time 0 represents the year 1998 and Time 30 represents the year 2038.





(6) Commissioned Solar Panels

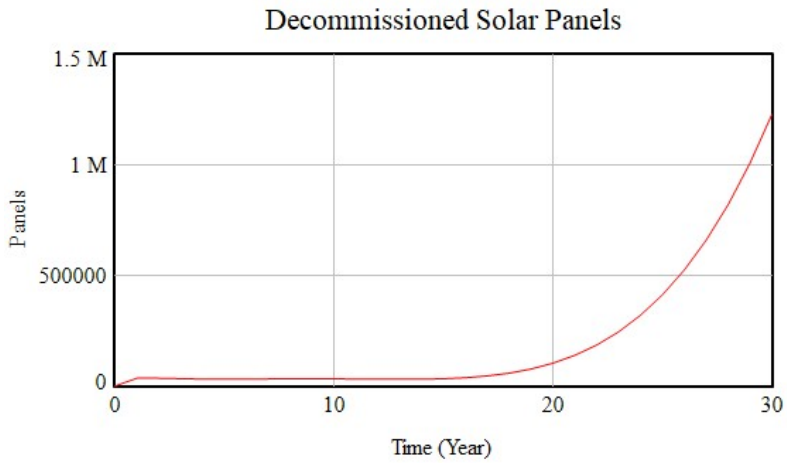
(7) Decommissioned Solar Panels

Based on this model, we now have a way of demonstrating the effects and potential of a full lifecycle SPR industry infrastructure that can be adjusted based on various considerations. This model is important in determining how fluctuations in SPR economics and legislation effect the capacity of the technology.

Maryland Case Study

To assess if our model could accurately predict the potential of SPR for various regions, as claimed, a case study was conducted for the state of Maryland (MD). Beyond the fact that this was the location of our research and funding, we felt this area would be a good example of why SPR infrastructure needs to be supported in even the smallest states that are not the top producers of solar power in the U.S. To adjust for the MD area, the input *Installation Rate* function needed to be fitted based on MD installations per year. Data from SEIA was taken for known values for 1998 to 2017 and predicted values for 2018 to 2023. The error of this function was calculated to be at most 30% initially, with the same decreasing error trend as time progressed. The overall error for this function was found to be substantially less than our function for the U.S. *Installation Rate*, which suggests that different regions may be either more or less accurate when applied to our model.

Using this function, we can get a strong estimate of the solar panel recycling needs of the area up until 2023. The results for estimated decommissioned panels is shown below:



(8) Decommissioned Solar Panel for MD SPR Infrastructure Model

We can see that the estimated rise of solar panels needing decommissioning is pushed back to a later date then the U.S.. This result makes sense, as MD isn't a top solar state and has not been at the forefront of solar installation in the U.S., as compared to states such as California or Arizona. However, since the 30 year time mark represents 2028, with over 1 million panels estimated to require decommissioning, we can determine that the need for SPR infrastructure in MD is still a valid concern. Based on the number of solar panel recycling facilities in the area being zero, this graph reflects if no solar panels are recycled. If this remains the case by 2028, an estimated 1.24 million panels will be sent to the landfill. However, with our model we can also predict how much could be recycled if there was a certain level of awareness, cost efficiency, and infrastructure developed in the area before then.

The Future of SPR

Based on the research and findings provided above, we are now able to accurately predict the capacity of solar panels in any region and assess the number of decommissioned panels that will be available by a certain date. This information should help to structure the infrastructure needed in the U.S. for SPR. The next step in this roadmap is determining where SPR facilities would best be located. A feasible recycling program for solar panels will require careful attention to the experiences of comparable industries and to the economics of collection and materials. The basic viability of any recycling program often hinges on the geographic concentration of the goods and their proximity to appropriate recycling facilities [4]. PV systems are not concentrated by nature as the industry is dominated by dispersed installations, such as off-grid power and standalone residential systems. To carry out the recycling process, a method for collection of the panels must be discussed. Logistically, collecting panels is more economically feasible for large, centralized installations. Pick up from various small kW capacity locations has shown to significantly increase the PV recycling process cost [4]. Ideally, it should be the utility's responsibility to transport decommissioned modules to recycling plants, however, there is currently no integrated process between utilities and module recycling companies to allow for this to happen. This concept has faced many challenges in the past due to the fallibility of solar companies who have unclear security in the future PV industry. Major solar companies such as SunEdision, BP Solar, and Sungevity have gone bankrupt despite being leaders in the field [16]. Increased producer responsibility for EoLT of solar generation sites will be required to insure the success of the SPR industry in the U.S., as demonstrated by PV Cycle in Europe.

CONCLUSION

By combining past research with the new considerations mentioned in this paper, we are now able to accurately predict the number of decommissioned panels that will be available by a certain date within any given region. This information will help to provide a roadmap for the SPR infrastructure needed in the U.S. This is essential as end-of-life considerations for solar power plants will become a significant concern in the next decade as more plants reach their decommissioning dates. The capacity of this new industry can now be predicted using a systems dynamics approach. The model itself uses discussed inputs such as installation rate of an area, awareness, infrastructure, and cost efficiency, along with background research to create a

versatile means for prediction. This research and data will help the industry prepare for the oncoming boom of decommissioned solar panels in the next decade.

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People

A CONCEPTUAL FRAMEWORK FOR THE ASSESSMENT OF HOUSING-RESIDENT FIT VIA THE CONCEPT OF ENVIRONMENTAL IMAGE

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Abstract

The long-term sustainability in residential environments depends strongly on a wide range of non-technological barriers mostly affected by people's perceptions. A human-based bottom up flexible decision-making approach has the potential for the successful implementation of environmental action plans via providing people's positive environmental perceptions and attitudes, enhancing their pro-environmental behaviours. Pro-environmental behaviour is a key concept not only in promoting the green selection of buildings' physical characteristics and the implementation of engineering, technological, and industrial sustainability achievements but also in improving residents' domestic activities. The bottom-up action plan, therefore, has substantial responsibility in the enhancement of Housing-Resident Fit, which improves the sustainability of the residential sector via occupants' spontaneous self-selection of green products and activities, providing a balanced interplay between occupants and their environment. This research refers to the concept of environmental image, which is the collective conceptual picture of end-users' environmental perceptions, to provide a suitable theoretical basis for developing a bottom-up action plan in housing. The environmental image makes it possible to quantify the abstract data; and hence provides a practical platform for dealing with the complexity of people's perceptions. This study has developed a conceptual framework, which explains a practical methodology for Housing Resident Fit via visually establishing occupants' housing image. According to the framework, studying occupants' housing perceptions would result in the identification of a set of attribute-based housing related factors and the reasons that make the factors critical to the occupants. The results assist in developing suitable intervention strategies, i.e., information strategies and structural strategies, which aim at eliminating the internal barriers (e.g. perception, motivation, attitudes, and social support) and external barriers (e.g. availability, product quality, costs and benefits, regulations, and measures) and promoting rewards. The developed strategies provide occupants' positive attitudes, which are tailored to their proenvironmental behaviours, ensuring long-term sustainable development.

INTRODUCTION

The building industry, with energy consumption up to 40% alongside Carbon Dioxide (CO_2) and Greenhouse Gases (GHG) emission of one-third, and a wide range of impacts on the area of humanity (United Nations Environmental Programme, Sustainable Buildings and Climate

Change (UNEP SBCI), 2009) has a substantial role in generating a variety of environmental impacts, e.g., global warming, climate change, poverty, justice, and equality (UN Foundation, 2015). The industry also has exceptional potential for short run costeffective enhancement (Allwood et al., 2012; Desmarais, Lawson, & Owen, 2013). Currently, in the industry, putting the main emphasis on industrial, engineering, and technological aspects with lack of attention to the impacts of human aspects on sustainability action plans results in a top-down approach implemented via a wide range of fixed rules. This approach to environmental sustainability not only detracts from the leverage of the plans but also leads to people's lack of attention to the implemented plans, overriding the outcomes and achievements of the plans (Beyond Zero Emissions (BZE), 2013; Intergovernmental Panel on Climate Change (IPCC), 2007; Centre for Climate and Energy Solutions (C2ES), 2015).

In Australia, this is a common phenomenon in the area of small-scale buildings, e.g., smallsize dwelling units, such as detached, semi-detached, and townhouse, in which the industry has a variety of different stakeholders; and a wide range of human factors which are the main driving forces in the successful implementation of the action plans. Therefore, sustainable development of small-size residential units in Australia depends strongly on developing a human-based bottom-up flexible approach (C2ES, 2015; Asad Poor & Thorpe, 2017). Given the potential of small-size housing to enhancing the sustainable development of Australia and the role of human factors in the successful implementation of action plans, this study intends to develop a practical conceptual framework, namely "Housing-Resident Fit" (HR Fit). The framework aims at enhancing environmental sustainability in the area of small-size residential buildings via providing a balanced interplay between occupants' motivations and environmental issues, e.g., energy consumption, GHG and CO_2 emission, and assisting end-users in selecting/achieving more congruent housing environment via visualisation of their housing sustainability perceptions. This aim would be achieved through assessing occupants' housing image (HI) via attribute-based representations of housingimages and the reasons that make the attributes critical to the occupants. In responding to this aim, an overview of literature was conducted to address a brief picture of housing-resident fit as the main conceptual platform of the study, which was then used to develop a conceptual framework of the study through a brief review of a number theoretical and empirical research works and studies.

LITERATURE REVIEW

A long-term sustainability action plan requires bottom-up flexible approach rather than topdown fixed rules, to provide a proper accountability and ambition through a broad participation (C2ES, 2015). The bottom-up flexible approach means the provision of a flexible right-based action plan that is able to give the right to people to express their needs and rightfully assist them in keeping their access to the different resources to meet these needs (Moser & Uzzell, 2003). The right-based approach by means of flexible and supportive rules and regulations has the potential to encourage people's pro-environmental behaviours and to increase their level of attention, active participation, and involvement in action plans by improving their positive attitudes to environmental factors (Moser & Uzzell, 2003; Ramkissoon, et al., 2012); thus enhancing the outcomes of the implemented plans. The concept of pro-environmental behaviour is defined as people's spontaneous involvement in the behaviours

that generate the minimum negative environmental impacts or result in positive environmental impacts (Ramkissoon, et al., 2012; Steg & Vlek, 2009).
Therefore, it is highly crucial to develop a practical methodology for a bottom-up humanbased flexible approach to sustainable development of the Australian building industry. The approach is crucial with respect to small-size residential units with up to 70% floor area and up to 55% energy consumption of the whole building sector (Asad Poor & Thorpe, 2017) and a wide range of impacts generated by a variety of human related factors (Jowsey & Kellett, 2012). In this area, indeed, the typological diversity of products, the diversity of stakeholders, the impacts of occupants' attitudes and preferences on the direction of housing development, as well as the spread and magnitude of households' domestic activities are the main sources in impacting the outcomes of sustainability action plans (Cheng, 2010; Levine, et al., 2007).

In the area of small-size housing, the diversity of end-users and typological variation of housing products are the main reasons for a large number of barriers rooted in end-users' perceptions and attitudes. The end-users' perceptions are key driving forces in impacting the direction of housing development by the selection of different physical and spatial characteristics of the dwelling units and the impacts of this selection on their domestic activities. In developing the bottom-up approach, the main challenge is how to deal with the complexity of human environmental perceptions or to develop a practical methodology to quantify/assess the environmental perceptions. In this regard, the concept of Environmental Image (EI) which is able to draw a concrete picture of collaborative/collective human environmental perceptions, established by Lynch (1960), provides a practical platform for visually addressing the environmental perceptions. The evolutionary progress of the implementation of EI in quantifying human environmental perceptions includes a wide range of empirical studies with different aims and scopes, various assumptions and conceptual practices, and different contributions and practical implications. The studies looked at the concept from an abstract (Chen, 2009; Zhou et al., 2014) to a practical viewpoint (Salesses, Schechtner and Hidalgo, 2013) and from an extroverted (visitor's point of view dealing with figurative aspects) (Zhou et al. 2014) to an introverted approach (user's point of view dealing with inhabitable aspects) (Salesses, Schechtner and Hidalgo, 2013). Some works studied the interior aspects (Chen, 2009; Durmisevic, 2002; Fisher-Gewirtzman, 2009), while others studied the exterior aspects (Salesses, Schechtner and Hidalgo, 2013; Patterson, et al., 2014; Zhou et al., 2014). Some studies explained the differences among the different groups of people, e.g. locals, insiders, outsiders, newcomers, visitors, and tourists (e.g. Zhou, et al., 2014). Despite the differences in their theoretical and conceptual assumptions and practical implications, these studies indicated the different potential contributions of EI in enhancing the different areas of environmental sustainability, e.g. city re-image, city identity recognition, neighbourhood safety and inequality (Chen, 2009, Zhou et al., 2014; Salesses, Schechtner and Hidalgo, 2013).

The central assumption in the recently conducted studies in the area of EI is based on the idea that believes pictures and photos encompass a wide range of information about the content of the visualised elements and objects (Patterson et al., 2014). Extraction of this content would have the potential to visually assess the human environmental perceptions in relations to different characteristics of the photos. In the context of this study, extraction of the content of environmental photos would result in the visualisation of attribute-based representations of the environmental characteristics, explaining human environmental perceptions. Patterson et

al. (2014) believed that unlike the traditional categorical-based representation, the attribute-based representation of the environmental characteristics makes it possible to explain the multifunctional and multidimensional content of the environment and to address intra-class variations due to the soft semantic categorisation; hence, makes it possible to interfere many of the unseen images. The possibility of the evaluation of unseen images provides a significant opportunity for developing an assessment methodology which is able to predict and recommend an environmental setting or a set of attribute-based factors which have the potential to meet the human perceptions.

The second practical contribution of the recent research works in the area of EI is the development of a particular computer-based methodology to automatically assess EI, which makes it possible to quickly run the analysis over a large data set. Extending the analyses over a large number of geo-tagged unseen images makes it possible to produce a GIS-based map from human environmental perceptions (Salesses, Schechtner and Hidalgo, 2013; Patterson et al., 2014; Zhou et al., 2014), which, would, in turn, provide a platform for developing a practical methodology for spatial data infrastructure (SDI) in the area of human perceptions. In the context of this study, addressing the potential of EI in enhancing the sustainability of small-size housing is the main concern. A suitable practical concept for clarification of the application of EI in enhancing small-size Housing sustainability is Person-Environment Congruence (PEC), stressing the congruity between environmental attributes and human motivational tendencies (Jusan, 2007). The essence of PEC is the provision of a dynamic balanced interplay between people's desires and environmental issues. This would be achieved through assessing the level of congruity between environmental attributes and people's motivational tendencies, assisting in the selection of more congruent attributes. Improving PEC has a crucial role in improving the spatial personalization alongside people's satisfaction and sense of place (Jusan, 2010), which results in improving pro-environmental behaviours and environmental sustainability (Ramkissoon, Weiler and Smith, 2012).

Encouraging pro-environmental behaviours in the context of this study facilitates the spontaneous selection of more congruent housing attributes and more responsible household activities, choice behaviours, and consumptions, improving the sustainability of housing sector. EI is a practical methodology for objectively addressing human environmental perceptions; and hence has the potential to be employed in visually assessing PEC in the area of small-size housing. Therefore, in this study the adoption of EI in assessing PEC has the potential to develop a conceptual framework namely "housingresident fit" (HR Fit), which is a platform for improving the dynamic balanced interplay between housing physical attributes and end-users' perceptions (Asad Poor, Thorpe and Yong, 2018). The concept of HR Fit is defined as the level of congruity between housing environment, e.g., neighbourhood, location, and building characteristics and end-users' perceptions. HR Fit would make it possible to determine/evaluate the level of congruity of the different housing attributes with end-users' housing perceptions to facilitate the selection of more efficient attributes whilst keeping the occupants' right in meeting their motivational tendencies and desires. The implementation of HR Fit, in this sense, would enhance the efficiency of physical and spatial characteristics of small-size housing, and occupants' domestic activities and choice behaviours, and pro-

environmental behaviours while considering their desires and motivations in the spatial organization of the environment. The next sections explain the conceptual framework in detail.

RESEARCH METHODOLOGY

To develop the conceptual framework of this study, an overview of a number of literature and research works was made to provide a practical methodology for dealing with human perception in the area of small-size housing and to explain how to facilitate the evaluation of HR Fit. This would be made based on a brief review of secondary data collected from a number of web-based sources. The main effort was to put all different information from different empirical studies together to explain the logic, function, process, and product of assessing and enhancing HR Fit through the developed conceptual framework of study.

ANALYSIS AND DISCUSSION

In dealing with the complexity of human perceptions in Australian small-size housing, it is highly essential to develop a practical conceptual framework, which has the potential to draw a concrete picture of occupants' housing perceptions (Asad Poor, Thorpe and Yong, 2018). As mentioned before, EI is a proper theoretical platform to bridge this gap by assisting in quantifying human environmental perceptions (Salesses, Schechtner and Hidalgo, 2013); hence, decreasing the complexity of dealing with human environmental perceptions. The concept of EI provides a suitable platform for an attribute-based representation of environmental characteristics based on the identification of semantic interrelationships among the different attributes.

Considering the potential implication of EI in quantifying human perceptions and in automatically assessing large number of unseen images, it is crucial to explain the potential contribution of the concept in developing a practical framework for HR Fit, which has the potential to represent the process and the outcomes of the evaluation.

Steg and Vlek (2009) developed a conceptual model namely "sustainable intervention strategies", aiming at encouraging pro-environmental behaviours, which would be also a suitable platform HR Fit. They indicated that sustainable interventions rely on: 1) identifying the behaviours that are critical in impacting environmental quality and the causal factors that generate these behaviours; 2) developing suitable strategies that have the potential to change the behaviours and their related antecedents; and 3) monitoring and evaluating the effect of the interventions on behaviours, environment, and people's quality of life. Therefore, identification of critical behaviour should be followed by addressing the causal factors (i.e. motivational, contextual, and habitual) to make it possible to develop suitable intervention strategies.

The intervention strategies might be informational strategies to change motivations, perception, attitudes, and social support (e.g., knowledge, awareness, information, values, commitment, social norms); or structural strategies to modify the circumstance, to remove the external barriers (e.g., availability, product quality, actual costs and benefits, legal regulations and measures), and to provide rewards.

The conjunction between EI and the conceptual framework of sustainable intervention strategies would result in developing a practical framework for HR Fit in small-size housing. Accordingly, HR Fit can be achieved by visually establishing end-users' Housing Image (HI), addressing the attribute-based representation of their housing preferences and choice behaviours. Establishing HI would result in identification of a set of attribute-based housingrelated factors and the causal factors (occupants' housing concern) that make the attributes critical to occupants; and then developing suitable intervention strategies for the enhancement of housing characteristics through the selection of more congruent attributes, which are able to provide a balanced interplay between occupants' motivations and desires and housing sustainability concerns. This conceptual framework is illustrated in Figure 1.

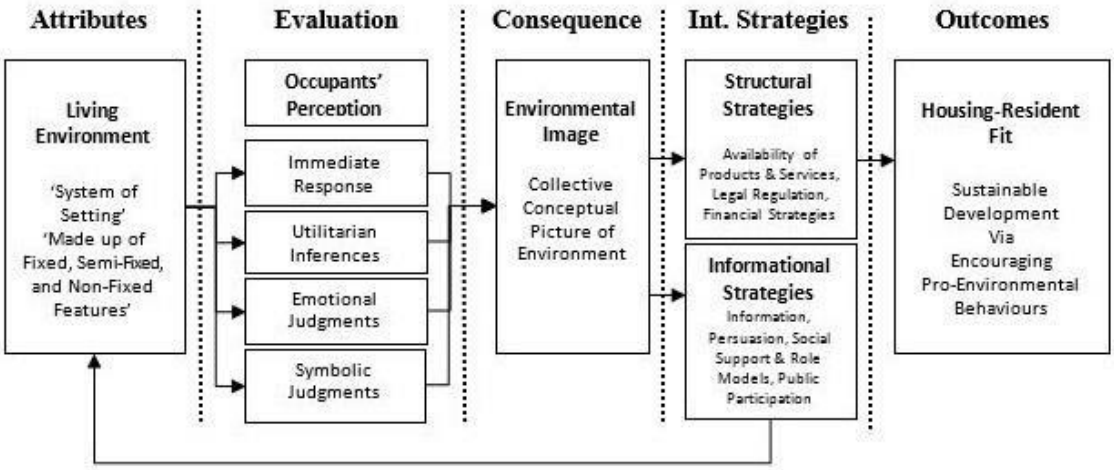

Fig 1. A developed conceptual framework of sustainable intervention strategies in small-size housing via the concept of Environmental Image

According to the framework, HR Fit is a consequence of the assessment of housing attributes via occupants' perceptions and then visually addressing their HI. The assessment would make it possible to explain the causal factors that are more relevant to occupants' perceptions and the housing attributes that are more significant in addressing the causal factors. Analysing the data collected from occupants' housing perceptions for a large number of housing photos would assist in drawing a collaborative conceptual picture of their housing perceptions, expressing the reasons and attribute-based factors which are more critical in their perceptions.

Establishing HI, therefore, assists in the visualisation of concerns, desires, and motivations, and the possible suitable strategies in meeting these expectations. HI in this sense is capable of assessing HR Fit for given residential units in relation to a particular individual. The evaluation of HR Fit provides a proper platform for developing suitable intervention strategies, i.e. informational and structural, to improve the housing characteristics in relation to occupants' desires and demands.

The photo-based assessment in addition would provide a practical platform to extend the analysis over a large number of geo-tagged housing photos, which in turn makes it possible to map the extracted attribute-based housing-related factors in different neighbourhoods and urban areas, representing residents' housing perceptions of different environmental sustainability factors, e.g., safety, energy efficiency. Mapping housing perceptions is capable of

providing a databank for a qualitative assessment of the housing characteristics (e.g., neighbourhood, location, building) in relation to occupants' perceptions. The outcomes of the assessments would be therefore tailored to a wide range of individual and public applications.

Based on the developed conceptual framework, therefore, the assessment of HI is an inevitable and critical stage in developing a sustainable action plan for enhancing the sustainability of small-size housing units in relation to a possible target end-user. In conjunction with the framework of sustainable intervention strategies, identifying HI would lead to the selection of two possible strategies. At the first level, if the established HI indicates that the causal factor is rooted in the lack of occupants' motivational tendencies (e.g. lack of knowledge, awareness, information, values, commitment, social norms), the most suitable strategy is to develop informational strategies, e.g. information, persuasion, social support and role models, public participation. Providing suitable information strategies would improve motivational tendencies and attitudes. If the assessment of HI indicates a proper level of motivation, then the enhancement of the causal factors would depend on the enhancement of the circumstance and the removal of external barriers, which in turn requires suitable structural interventions, e.g., availability of products and services, adjustment of legal regulations, provision of financial intensives and sources.

For instance, in the assessment of energy efficiency image of a dwelling unit, a photo-based assessment of occupants' perceptions in relation to the impacts of housing attributes on the housing energy efficiency would assist in addressing the end-users' perception of the impacts of the housing attributes on housing energy efficiency and the related causal factors. Conducting the analysis over a large number of housing photos would assist in addressing a collaborative image of housing energy efficiency from occupants' point of view, which provides attribute-based representations of the occupant's perceptions, explaining the causal factors and physical characteristics that are more relevant with a particular enduser; and hence, assists in identifying a range of physical characteristics and suitable intervention strategies that are capable of meeting the extracted desires and concerns.

The drawn image for instance would make it possible to underline which aspects of the energy efficiency are more critical in impacting occupants' perception; and hence would assist in explaining the causal factors in impacting the occupants' energy efficiency preferences and choice behaviours. This image would also help in drawing a concrete picture of the role of different housing attributes in enhancing the energy efficiency of dwelling units. Putting both layers together would be beneficial in better understanding the residents' concerns, interests, limitations, and worries, assisting in the prediction of more relevant environmental and building characteristics and the aspects that are able to provide a better response to a given occupant. This area of HI would also assists in the selection of more beneficial and suitable information and structural strategies, which are able to encourage and facilitate the occupants' pro-environmental behaviours and active involvement to the sustainability action plan.

CONCLUSION

The concept of EI has the potential to visually establish human environmental perceptions, and hence is a suitable methodology for practically addressing occupants' housing perceptions. Addressing HI would make it possible to address an attribute-based representation of housing characteristics, explaining the level of congruity between housing physical attributes and end-

users' motivations; and hence assist occupants in the selection of more congruent attributes, which provide a suitable platform for HR Fit and housing sustainable development. The HI assessment has the potential to assist more sustainable housing selections by providing the possibility of enhancing the congruity between occupants' desires and housing characteristics and also by generating a practical platform for spatial qualitative data infrastructure in the area of human environmental perceptions. The first idea would be probably developed through the possibility of evaluating a large number of unseen images, while the second one would be probably realised by a GIS-based map generated from the analysis conducted over a large number of geo-tagged housing images via an automated computer-based methodology using artificial intelligence. The first product would help end-users' to achieve and/or build more congruent living environment, while the second product would assist public sector to have a visual database of occupants' housing perceptions.

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TENANTS' WILLINGNESS TO PAY FOR GREEN FEATURES IN OFFICE PROPERTIES

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Keywords: Environment, Green features, Office properties, Willingness-To-Pay.

Abstract

The purpose of this study is to investigate tenants' willingness to pay for green features in office properties in Lagos, Nigeria; this is with a view to determining the inclinations of users for green buildings. Data for the study were collected through the use of structured questionnaire administered using purposive sampling. Tenants' Willingness To Pay Index (TWTPI) was used to measure the level of willingness to pay for features of green building by the tenants. The features considered are 'Water, Rain Water and Sewage', Site Selection, Site Design and Land Scape Ecology', 'Building Ecology, 'Waste and Recycling', 'Indoor Air Climate', Material use and Conservation', and Owner and Occupant Education'. A survey of office property tenants finds that majority (94.6%) were willing to pay between 1-5% more for green features. The willingness of tenants to pay for features such as 'Energy Conservation', 'Water, Rain Water and Sewage' and 'Site Selection, Site Design and Land Scape Ecology' ranked first, second and third with TWTPI of 3.12, 2.72 and 2.71 respectively. The paper advocates for relevant agencies to embark on aggressive awareness campaign which emphasizes the direct benefits of green building.

INTRODUCTION

The turn of the century has witnessed an increasing concern for sustainability in real estate industry, with major stakeholders: investors, developers and users trying to embrace sustainability agenda (RICS, 2010). While the concern may be partly attributed to global focus and advocacy for sustainable investment, the additional benefits and costs that may be incurred by investing or occupying sustainable or green building have combined to produce a formidable force for driving sustainability agenda in real estate industry. Investment in green buildings has been encouraged through government legislation in most developed economies. However evidence in literature suggests that the response by the private sector has been slow owing to lack of evidential proof of economic viability of green building investment (Myers, Reed and Robinson, 2007). Meanwhile, the willingness of tenants (space consumers) to pay and the extent to which they are willing to pay for green features is a major concern of the developers and investors particularly in emerging economies at present. Whether the tenants are willing to pay additional costs for green building or not has been a main subject of sustainable investment literature of a recent (see for instance, Banfi *et al*, 2008; Wiencke, 2013 and Simons *et al*). Such information is demonstrably valuable in providing an improved understanding for the potential and viability of green building investment. Sustainability in property investment, particularly the willingness to pay for green features has to date been

dominated by developed economies such as the United States of America, the United Kingdom and Australia. Evidence from literature shows that the majority of the studies was carried out in the developed economies where strong advocacy for sustainable development exists. Few studies have been carried out in developing and emerging countries like Nigeria. Meanwhile, sustainability as reasoned by Krosinsky and Robins (2008) has more urgent priorities among world's growing countries. This study therefore bridges the observed omission by investigating the tenants' willingness to pay for green features in office properties in Lagos, Nigeria.

LITERATURE REVIEW

Studies relating to willingness to pay for green features abound. Grosskopf (2003) examined the extent to which capital construction costs and life-cycle return on investment influenced tenants' willingness to pay for green building alternatives in Florida. The author complemented the performance of more than 100 high efficiency buildings simulated in the three major climatic regions to a consumer willingness-to-pay survey of more than 400 new home buyers. The result showed that willingness to pay for soft cost benefits excluding hard cost returns vary widely from 33.8% to 61.1%. The result also suggested that willingness to pay decisions of respondents vary mainly by age and income. Yau (2012) examined residents' willingness to pay and preferences for green housing features in Hong Kong. The author employed structured questionnaire survey and found that apart from moral or altruistic reasons, residents' willingness to pay was largely influenced by monetary incentives. The study also revealed that residents were more willing to pay for features directly linked with reduction in utilities bills. However, it should be noted that the investigation was carried out on residential property investments and not office properties.

Kitchen, Boyle and Leiserowitz (2013) estimated the willingness to pay in support of a national climate-change policy that was akin to the costs of actual legislative efforts in the U.S congress. The authors carried a survey of 2034 American adults and found that households were willing to pay between 79 and 89 dollars per year in support of reducing domestic green house gas emission. Apart from the fact that the study was carried out in a developed economy, the study did not specifically targeted office property users. Wiencke (2013) investigated the firms' willingness to pay for green features in Switzerland. The author employed data from corporate real estate and sustainability survey and found that Swiss corporations were willing to pay a premium price of 3.0% for leasing, 4.75% for purchasing and 5.0% for retrofitting. The result also showed that firms from building and financial service industries as well as public corporations and authorities indicated the highest willingness to pay. Simons, Lee, Robinson and Kern (2014) examined office tenants' willingness to pay for green features in the United States of America. The study considered eighteen (18) green building features and discovered that tenants were willing to pay a premium of 9.3% on office buildings. The result also indicated that the tenants' level of willingness to pay ranked highest for improved indoor air quality and access to natural light.

Park, Hagishima, Tanimoto and Chun (2013) investigated consumers' willingness to pay for certain green features of residential buildings in Seoul. The authors employed conjoint analysis and ranking method found that the marginal willingness to pay for 1% reduction of carbon dioxide emission was estimated about 377 USD, two times higher than that for reduction of

VOC emissions and almost the same as that for the reduction of energy bills. The result also indicated that energy bill was most preferred while IT facilities were the least preferred by the residents. Although the study was carried out in an emerging economy, the study did not consider office property users.

Zalejska-Jonsson (2014) measured the stated and rational willingness to pay for green apartment in Sweden. The study considered the responses of residents of green and conventional multifamily buildings to investigate the existence of willingness to pay and to test the difference in the perception of those living in green and those living in conventional building. The result showed that respondents were willing to pay for green building but not as willing to pay for buildings with environmental certificate.

RESEARCH METHOD

In order to investigate the tenants' willingness to pay for green features in office properties, the study employed data collected through questionnaire from the tenants of office properties in the management portfolio of estate surveying and valuation firms in Lagos in Lagos, Nigeria. In total 88 (representing 20% of 440 estate surveying and valuation firms in the study area) were sampled for ease of coverage. In the administration of questionnaire, 2 office properties were sampled purposively from the portfolio of each sampled firms. In each selected property, two tenants were selected purposively from each sampled property. Thus, a total of 352 tenants in 176 properties were selected for sampling. In earlier works by the authors (Komolafe and Oyewole, 2015 and Komolafe, Oyewole and Kolawole, 2016), building attributes with energy conservation; indoor air climate; material use and conservation; water, waste and waste recycling; site selection, site design and landscape ecology and owner and occupant education features were identified as green features. These features constitute variables used in this study.

The respondents were asked about their socio economic characteristics; their perception as to whether they were willing to pay; their level of willingness and the amount they were willing to pay for the respective green features. The tenants were further asked to rate each of the features using likert's scale of *not at all willing, willing to pay a cost premium 1-5%, willing to pay a cost premium of 6-10%, willing to pay a cost premium 11-20%, willing to pay a cost premium 2130% and willing to pay a cost premium of above 30%*. During analysis, these ratings were assigned weight values of 1, 2, 3, 4, 5 and 6 respectively. The tenants' willingness to pay index (TWTPI) for each of the variables was arrived at by dividing the summation of weight value (Total weight value – TWV) by the total number of respondents. The TWV is the addition of product of the number of responses to each of the variables and the weight values attached to each rating (see Afon, 2000 and Oyewole, 2010). The TWTPIs thus ranged between the values of 6 and 1. This is expressed mathematically as:

$$TWV = \sum_{i=1}^{6} P_i V_i \quad \text{.....(1)}$$

Where TWV is the total weight value, P_i is the number of respondents rating an attribute i; and V_i is the weight assigned to each attribute i.

The TWTPI to each attribute is arrived by dividing TWV by the summation of the respondents to each of the six ratings of an attribute. This is expressed mathematically as:

$$T_{WTPI} = \frac{TWV}{\sum_{i=1}^{6} P_i} \quad \ldots\ldots(2)$$

Where RWTPI is the relative willingness index and P_i is as defined previously. The closer the TWTPI of an attribute is to six, the higher the assumed relative willingness. The mean of the TWTPI distribution was computed. The deviation about the mean of each variable was also computed to measure the scatter in the data relative the mean.

RESULTS AND DISCUSSION

In presenting the results of the study, the paper first examined the characteristics of tenants and subsequently on their level of willingness to pay for green features.

Characteristics of Tenants

The characteristics of office properties' tenants are as shown in Table I below. The result shows that majority of responding tenants are males (59.8%), whose ages range between 31 and 40 years (35.3%) with first (HND/B.Sc) degree (41.1%). The result also reveals that majority of the respondents were senor staff (29.0) with between 6 to 10 years of experience. The analysis of the occupation of the respondents indicates that they were engaged in various activities such as professional services, financial services, recruitment and training, business services and manufacturing. The result further reveals that majority of the respondents (44.8) were engaged in business services, while 27.4%, 12.9%, 7.5%, and 7.5% were engaged in professional services, financial services, recruitment and training and manufacturing activities respectively.

Table I: General Characteristics of Tenants

Characteristics	Frequency	Percentage
Gender		
Male	144	59.8
Female	97	40.2
Total	241	100.0
Age		
20-25	30	12.4
26-30	67	27.8

31-40	85	35.3
41-50	33	13.7
51 and above	8	3.3
No response	18	7.5
Total	241	100.0

Highest Educational Qualification

O' level certificate	19	7.9
ND	90	37.3
HND/BSc	99	41.1
Masters	18	7.5
PhD	0	0.0
No response	15	6.2
Total	241	100.0

Occupation

Professional services	66	27.4
Financial services	31	12.9
Recruitment and training	18	7.5
Business services	108	44.8
Manufacturing	18	7.5
Total	241	100.0

Official Designation

Business Owner	28	11.6
General Manager/Assistant	31	12.9
Sectional Head/assistant	46	19.1
Senior Staff	70	29.0
Junior Staff	48	19.9

No response	18	7.5
Total	241	100.0

Years of Experience		
1-5 years	125	51.9
6-10 years	70	29.0
11-20 years	29	12.0
above 20 years	2	0.8
No response	15	6.2
Total	241	100.0

Tenants' willingness to pay for green features

This section examines the willingness of users to pay for green building features and compares their willingness to pay for each feature with the relative preference attached to the corresponding green features. The result shows that 94.6% of the respondents were willing to pay for green building features while 5.4% were not willing to pay. The finding indicates a high rate of tenants' willingness to pay for green features and is contrary to Oladokun *et al* (2010) which revealed that most of the users were unwilling to pay extra payment for green building.

The willingness of the responding tenants to pay is further examined across the categories of green features examined earlier. The result on the cost premium willing to be paid on each category by the users is as presented in table II. The tenants' level of willingness to pay for green features was assessed. This is through tenants' willingness to pay index (TWTPI), computed for each of the green features.

The result in Table II shows that majority of the features have a TWTPI of less than 3 (out of 6). This indicates that the level of willingness of tenants to pay for majority of green features in the study area was very low. The study also reveals that features that rank high in terms of TWTPI are 'energy conservation' (3.12) and 'water, rain water and sewage' (2.72). This finding might not be unconnected with severe challenges in the area of power supply and water faced by users (Oyewole and Komolafe, 2018). Office property users in the study area depend mainly on public power supply which is erratic in supply necessitating the provision of additional source of power. The tenants might also be willing to pay for water saving facilities in order to ration the use of water which is considered essential for their daily usage.

The analysis on green features relating to energy conservation shows that 'Availability of contingency plans for power supply' attracts the highest TWTPI of 4.87 while 'Growing of natural vegetation in the surrounding environment attracts the lowest TWTPI of 1.97. The average TWTPI for this group of features is 3.12. Other features with TWTPI higher than average are 'Installation of low-basic energy lighting' (4.01),'Design for low energy intensive inhouse and public transportation' (3.45), 'Energy recovery ventilation systems' (3.35) and 'Use of natural cooling systems' (3.15). Each of the features in this category thus had a positive deviation about the mean. The implication of this is that the degree of willingness to pay for these features is higher than average level of willingness the tenants had to pay for green features relating to energy conservation. Further analysis indicates that six of these features had negative deviation about the mean of TWTPI. These features are 'Use of natural cooling systems', 'Use of solar cells, winds or photovoltaic means for power supply', 'Use of natural lighting systems', Maximizing the contribution of passive solar energy without reducing the comfort in periods with high solar exposure', 'Energy optimized windows', Design for energy efficient deconstruction and recycling' and Growth of natural vegetation in the surrounding environment'. The deviations about the mean of TWTPI for features relating to energy conservation for the above listed features are -0.11, -0.28, -0.37, -0.38, -0.94 and -1.15 respectively. The result of the study on features relating to 'Water, rain water and sewage' reveals that 'Water saving toilet and bath facilities' shows that the highest WTPI is 4.55 while the least is 1.94. The feature with the highest WTPI was 'Water saving toilet and bath facilities' while design for dual plumbing had the lowest. The average TWTPI for features in this category is 2.72. Other feature with TWTPI higher than the average for this group of features is 'Water efficient plumbing features' with TWTPI of 3.84. Features such as 'Collection of rain water for Utilization to lessen pressure on portable water', 'Waste water reutilization', Pressure reducing mechanisms on the plumbing features' and 'design for dual plumbing features' had a negative deviations about the mean of group of features in this category. A glance at the result also shows that the aforementioned features with negative deviations also attracted TWTPI of less than average (less than 3 out of maximum 6) implying that the level of tenants' willingness to pay for the features was low.

Regarding features relating to 'Site selection, site design and landscape ecology', 'Access to public transport within reasonable time' attracted the highest TWTPI (4.25), followed by 'Good lighting controls' (3.55), while 'A green common area is included in the main plot attracted the least TWTPI (1.98). The average TWTPI for this category of green features is 2.71. Other features with TWTPI higher than the average of all features in the group are 'Space sufficiency' (3.50) and 'Design is flexible to allow for easy conversion' (3.45). The finding as revealed in the table shows that the willingness of tenants to pay for most (eight) of features in this category of green features is below average (3 out of 6).

Among features relating building ecology, waste and recycling, 'Control of site pollution' attracted the highest TWTPI (4.15) among features as most tenants were willing to invest in properties with features that would enable them to safeguard pollution with a view to ensure that their offices are located in an area 'free from contamination' which ranked next with TWTPI of 4.12. The average TWTPI for the green features relating to 'building ecology, waste and recycling' was 2.64. Other features with TWTPI higher than the average included 'Right channelization of water drain' (3.95) and 'Availability of storm water management measures'

(2.95). Features with TWTPI lower than the average of this category of features included 'Noise from installations is kept moderate and under control' (2.45), 'Waste water is treated from sinks and showers' (2.12),' Means of waste diversion from living areas where it could be toxic' (2.08),' Facilities for Storing and Handling Recyclable Materials' (2.01),' Measures to ensure that food or food waste is well contained' (1.95),' Collection points for sorting wastes into paper, glass, metal and plastic for treatment' (1.90) and 'Construction, renovation and demolition waste management policy' (1.36). Each of the features in this category thus had a negative deviation about the mean of TWTPI of features relating to 'Building ecology, waste and recycling'. The

implication of this is that the degree of willingness of tenants to pay for these features is lower than the average of their willingness to pay for green features relating to building ecology, waste and recycling. The result of analysis on green features relating 'Indoor air climate' shows that TWTPI of most of the features was below average (3.00) and also attracted negative deviations about the mean of TWTPI (2.38) of the group. Location of air intakes far from sources of pollution' attracted the highest TWTPI (4.39) followed by 'Building design to utilize natural and cross ventilation' (3.43). Other features such as 'In-door materials that are less air-toxic', 'Mechanical ventilation of enclosed parking areas', 'Building effective local exhaust into heavy equipment rooms', and 'A building design which avoids the need for air condition/cooling systems' (1.15) had TWTPI lower than the average and negative deviations of -0.37, -0.50, -0.95 and -1.23 respectively. The results show that features not directly associated with occupants comfort had TWTPI lower than the average suggesting that tenants had low priority for the features.

Among features relating to 'Materials use and Conservation', 'Availability of equipments on-site to deal with environmental emergencies' ranked highest in terms of TWTPI (3.51) followed by 'use of durable materials' (TWTPI = 3.15) while 'Avoidance of Foam materials using CFC and HCFC' ranked least with a TWTPI of 1.44. The average TWTPI for this category of green features is 2.21. Further analysis indicates that five of these features have negative deviations about TWTPI of green features relating to 'Materials use and Conservation'. These features are 'Use of materials that protect against the local weather conditions', 'Water installations, cable works and related installations without toxic PVC', 'Use of recyclable/recycled materials in construction', 'Use of natural and local materials in construction' and 'Avoidance of Foam materials using CFC and HCFC'. The implication of this is that the level of willingness of tenants to pay for these features is lesser than the average level of willingness to pay for 'Materials use and Conservation'. The deviations about the TWTPI for that category of features are -0.06, -0.15, -0.56, -0.70 and -0.77. The level of willingness to pay expressed by respondents on 'Availability of equipments on-site to deal with environmental emergencies' is not unexpected as the tenants who were involved in various business activities, would always be willing to make provision for the protection of their lives and properties.

The aggregate (mean) of tenants' level of willingness to pay for features relating to 'Owner and Occupant Education' is 1.84. Further analysis indicates that two features have positive deviation about the mean of TWTPI of features relating to 'Owner and Occupant Education'. These features are 'Availability of regular procedure for checking and fixing leaks' (2.41), 'Availability of checklist of items connected to Indoor Air Quality that must be discussed with architects, engineers, contractors, and other professionals prior to renovations and repairs' (1.97), 'Availability of regular maintenance schedule' (1.87) and 'Availability of Emergency response

Manuals' (1.85). The result reveals that all features in this category of green features attracted TWTPIs that are lesser than the average (3.0 out of 6.0). The implication of this is that the level of willingness of the respondents to pay for these features was low.

Table II: Tenants' Willingness for Green Features

Green features	TWTPI	TWTPI – TWTPI	Ranking
Energy Conservation			**1**
Availability of contingency plans for power failure	4.87	1.75	1
Installation of low-basic energy lighting	4.01	0.89	2
Design for low energy intensive in-house and public transportation	3.45	0.33	3
Energy recovery ventilation systems	3.35	0.23	4
Use of natural cooling systems	3.15	0.03	5
Use of solar cells, winds or photovoltaic means for power supply	3.01	-0.11	6
Use of natural lighting systems	2.84	-0.28	7
Maximizing the contribution of passive solar energy without reducing the comfort in periods with high solar exposure	2.75	-0.37	8
Energy optimized windows	2.74	-0.38	9
Design for energy efficient deconstruction and recycling	2.18	-0.94	10
Growth of natural vegetation in the surrounding environment	1.97	-1.15	11
	3.12		
Water, Rainwater and Sewage			**2**
Water saving toilet and baths facilities	4.55	1.83	1
Water efficient plumbing features	3.84	1.12	2
Collection of rain water for Utilization to lessen pressure on portable water	2.03	-0.69	3
Waste water reutilization	2.01	-0.71	4
Pressure reducing mechanisms on the plumbing features	1.95	-0.77	5
Design for dual plumbing	1.94	-0.78	6
	2.72		7
Site Selection, site design and land scape ecology			3
Access to public transport within reasonable time	4.25	1.54	1
Good lighting controls	3.55	0.84	2
Space sufficiency	3.50	0.79	3
Design is flexible to allow for easy conversion	3.45	0.74	4
Availability of controllable internal or external blinds and light fixtures that prevent glare at Visual Display Terminals	2.45	-0.26	5
Shading of glazing (windows) is achieved when necessary	2.43	-0.28	6
Building design allows for non-destructive inspection	2.42	-0.29	7

Sufficient acoustic privacy	2.30	-0.41	8
Ease, in open office areas, to engage in a conversation using a normal voice, understand a phone conversation, and have a private conversation using lowered voices	2.16	-0.55	9
The design is planned for an easy access to technical installations	2.08	-0.63	10
Sustainable landscaping	2.00	-0.71	11
A green common area is included in each main plot of land	1.98	-0.73	12
	2.71		
Building Ecology, Waste and Recycling			**4**
Control of Site Pollution	4.15	1.51	1
Freedom of building area from contamination	4.12	1.48	2
Right channelization of water drains	3.95	1.31	3
Availability of storm water management measures	2.95	0.31	4
Noise from installations is kept moderate and under control	2.45	-0.19	5
Waste water is treated from sinks and showers	2.12	-0.52	6
Means of waste diversion from living areas where it could be toxic	2.08	-0.56	7
Facilities for Storing and Handling Recyclable Materials	2.01	-0.63	8
Measures to ensure that food or food waste is well contained	1.95	-0.69	9
Collection points for sorting wastes into paper, glass, metal and plastic for treatment	1.90	-0.74	10
Construction, renovation and demolition waste management policy	1.36	-1.28	11
	2.64		
Indoor Air Climate			**5**
Location of air intakes far from sources of pollution	4.39	2.01	1
Building design to utilize natural and cross ventilation	3.43	1.05	2
In-door materials that are less air-toxic	2.01	-0.37	3
Mechanical ventilation of enclosed parking areas	1.88	-0.50	4
Building effective local exhaust into heavy equipment rooms	1.43	-0.95	5
A building design which avoids the need for air condition/cooling systems	1.15	-1.23	6
	2.38		
Materials use and Conservation			**6**
Availability of equipment on-site to deal with environmental emergencies	3.51	1.3	1
Use of durable materials	3.15	0.94	2
Use of materials that protect against the local weather conditions	2.15	-0.06	3
Water installations, cable works and related installations without toxic PVC	2.06	-0.15	4
Use of recyclable/recycled materials in construction	1.65	-0.56	5
Use of natural and local materials in construction	1.51	-0.70	6

4Avoidance of Foam materials using CFC and HCFC	1.44	-0.77	7
	2.21		
Owner and Occupant Education			**7**
Availability of regular procedure for checking and fixing leaks	2.41	0.57	1
Availability of checklist of items connected to Indoor Air Quality that must be discussed with architects, engineers, contractors, and other professionals prior to renovations and repairs	1.97	0.13	2
Availability of regular maintenance schedule	1.87	0.03	3
Availability of Emergency response Manuals	1.85	0.01	4
Availability of readily available operating manual covering standard control settings and operating instructions for all services equipment that may affect the energy consumption	1.84	0.00	5
Availability of documented measures to control pollutants at source in areas such as washrooms, kitchens, printing areas, chemical storage and general storage areas	1.82	-0.02	6
Availability of communications to tenants on the environmental measures that they can implement in the building	1.80	-0.04	7
Availability of Waste Reduction Work plan	1.78	-0.06	8
Regular check of outdoor air intakes to ensure that the openings are protected and free from obstruction.	1.75	-0.09	9
Availability of tenants' sub-metering (On energy, water, etc.)	1.72	-0.12	10
Availability of carbon dioxide monitoring or sensors to maintain pre-set levels of carbon dioxide.	1.65	-0.19	11
Availability of "Use & Maintenance" manual	1.62	-0.22	12
	1.84		

CONCLUSION

The study has provided information on the willingness of office property tenants to pay for various categories of green features. The aim is to evaluate the desire and readiness of tenants (office space users) to invest in green buildings. The degree of willingness of tenants to pay for for various categories of green features was assessed through tenants' willingness to pay index (TWTPI). Moreover, the objective was to gain insight into the preparedness of office space users to embrace green buildings in the country. The study found that tenants were more favourably disposed and willing to pay for green features that confer comforts to occupants rather than those that confer benefits to the environment. This finding is not unexpected and in line with the outcomes of the earlier studies (Komolafe and Oyewole, 2015; Oyewole and Komolafe, 2018) on the preference of users for green features. The implication of this is that the tenants were more inclined to pay for features that confer occupants comforts such as 'Availability of contingency plans for power failure', 'Water saving toilet and baths facilities', 'Access to public transport within reasonable time', and 'Location of air intakes far from sources of pollution', it is recommended that tenants should be educated on the importance of features that are eco-friendly in order to enhance the sustainability of built environment.

The study also established that the willingness of tenants to pay for most of the groups of green features was low. Most of the features such as 'Water, Rainwater and Sewage' (2.72),' Site Selection, site design and land scape ecology' (2.71), 'Building Ecology, Waste and Recycling' (2.64), 'Indoor Air Climate' (2.38), 'Materials use and Conservation' (2.21) and 'Owner and Occupants' Education' (1.84) attracted TWTPI of less than the average (3.0 0ut of 6.0). efforts should therefore be intensified to educate the tenants on the benefits of the features. It was also discovered that some green features such as 'Design for dual plumbing', Construction, renovation and demolition waste management policy', and 'Availability of use and Maintenance manual' ranked low in terms of tenants' willingness to pay. This might not be unconnected with what Oyewole and Komolafe (2018) ascribed as the level of importance of such features to management rather than tenants who might not have property management responsibilities. There is therefore the need to educate the users on the importance of such features to achieving full sustainability of built environment.

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AFFORDABLE HIGH PERFORMANCE HABITAT FOR HUMANITY HOMES

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Keywords: High Performance, Passive, Green, Energy Efficient

Abstract

Currently, there is no universal definition of a "high-performance home" in the residential industry. However, there is some consensus in the way that it is measured or performs. Various institutes or certifications have helped establish what constitutes a "high performance home" including but not limited to Passive Haus, Energy Star, HERS, and Net Zero Ready Homes. These certifications have provided a basis from which we can measure how high performing a home really is. According to the New Home Stakeholders Group (Colorado), high performance means setting a higher bar for "comfort, durability, indoor air quality, and lower energy use." Meanwhile, the Appraisal Institute (a global association of real estate appraisers) says the term suggests energy efficiency, sustainability, and the use of environmentally friendly products. The missing element in the equation of whether "high-performance home" is just another form of "green washing" or "marketing strategy" is how affordable design and construction techniques can be. A case study of how a Habitat for Humanity affiliate in Ogden, Utah designed and built a "high-performance affordable home" will be discussed. The home is "super insulated" and employs affordable passive solar design features along with state of the art air sealing techniques to earn the title of affordable true cost of home ownership.

BACKGROUND

Habitat for Humanity (HFH) is an international organization whose mission is to build "decent, affordable houses" at no profit. The organization was founded under the concept of "partnership housing" centered on those in need of adequate shelter working side by side with volunteers. Habitat for Humanity was founded in 1976 and sprung onto the international stage when President Jimmy Carter and his wife Rosalynn raised awareness. Habitat now works in nearly 1,400 communities across the U.S. and in approximately 70 countries and has helped more than 13 million people achieve, strength, stability and independence through safe, decent and affordable shelter. The local Utah Davis/ Weber Counties affiliate for HFH constructs 1-3 homes a year primarily in the dilapidated downtown Ogden area. www.habitatwd.org The families are selected based on three criteria; First, the family must have a need, second, the family must be willing to partner with HFH, and third, the family must have the ability to pay affordable monthly payments. Those families who meet these qualifications help build and put in "sweat equity" hours towards their new Habitat home. Additionally, families go to budgeting classes. The monthly mortgage payments go into a revolving fund to help another family in the future. The motto HFH lives by is to "Give a Hand Up, Not a Hand Out".

All of the home sites are gray field development sites. The last two Habitat homes built in Ogden have been designed and overseen by Weber State University (WSU) students and faculty. Previous homes built by this affiliate were constructed without concern for the true cost of ownership including energy and maintenance costs. The only consideration was the initial cost, and those homeowners are paying between $150 to $250 monthly in electricity and natural gas bills, and up to $50 per month for maintenance related costs. This has put some of the families in a precarious financial burden that could have been avoided. The strategic decision has been made that the affiliate would rather invest in energy saving design strategies to minimally increase the initial costs of construction, but significantly reduce the monthly true cost of ownership.

INTRODUCTION

As a professor teaching sustainable building design & construction, I needed a way to provide real-world learning experiences for my classes to engage them more effectively. Instead of working through fictitious design problems, we tackled the need for affordable high performance homes that would provide a lower true cost of ownership for recipients of these decent and affordable houses. We felt that by reducing the cost of ownership by $100-$150 per month, we could get more deserving families into homes. Working with HFH provided historical data to base design decisions off of as well the opportunity to research the impact of design changes on homes designed and constructed by my students and other volunteers. A simple return on investment calculation was established to quantify if high performance practices would be implemented. Because HFH sells the homes at no interest, the return on investment just had to be greater than $2.78 per month for every $1,000 spent in energy efficient upgrades. ($1,000/360 months = $2.78) Within reason, this became our basis for implementing high performance products and systems. The current model is to run a student competition to design the next HFH home to be constructed in my second semester Residential Design & Codes class. The Executive Director and Construction Manager for Habitat come in to my Residential Design class at the start of the semester and provide a specific lot, family demographic, and design requirements for the students to use as their parameters. We host field trips to previous homes and to the lot where the home they will be designing is set to be built. The students spend the remainder of the semester designing a home to meet the specified requirements and HFH staff judge the student designs as the final oral defense for the course. These top home designs are then used in my Sustainable Building Design & Construction class to evaluate product selections, Energy Efficiency, HVAC system design, Passive Solar design, Building Envelope design, and resiliency. We run the designs through energy code simulations such as ResCheck, BeOpt, and Rem-Rate (HERS) to estimate the true cost of ownership and to solidify design selections such as appliances, lighting, HVAC systems and other building envelope products that affect energy consumption. Some groups have used the Department of Energy's BeOpt software that helps identify the most cost optimal options such as wall types, insulation levels, etc. Additional Building Performance analysis is done through Autodesk software and the Autodesk Building Performance Analysis online course. Modules include; Energy Literacy & Building Loads, Climate & Weather Analysis, Solar Measurements & Strategies, Wind & Airflow Strategies, Daylighting Strategies & Analysis, and Whole Building Energy Optimization.

CONTEXTUAL REVIEW

According to Andrew Spofford, chief of staff at the nonprofit Preservation of Affordable Housing (POAH), right now the U.S. is "serving something like one in four families that really need housing assistance". Cohen, Nancy The National Low-Income Housing Coalition has identified a shortage of 7.4 million homes that are affordable and available. More than eight million extremely low income households pay more than half of their income to rent their homes. Cohen, N. E. (2017, Oct. 9) "People with low incomes are the ones who need it the most," referring to why sustainable design advocates argue affordable housing should be energy efficient, healthy, and durable says Krista Egger, director of initiatives at Enterprise Community Partners (ECP). Laurel Blatchford, senior vice president and chief program officer for ECP says the myth that sustainable housing is, in her words, "wildly boutique and expensive" isn't true. "What we see across the country again and again is those investments that are made in greener, more sustainable technologies or improvements really see enormous benefits over the life of a project." Blatchford continues, "From our perspective, it's not only better for the environment; the operating costs are lower, which means it's more likely the tenant will continue to have affordable rent." According to most government affordable housing programs, an affordable home is defined as no more than 30% of a given households income. Federally funded affordable rental housing targets households earning 60% of the Area Median Income (AMI), whereas homeownership targets household earning 80% of AMI and below. (Cohen) We used a similar approach to define a baseline of what would be considered "affordable" in our community based on an adjusted AMI for Ogden, Utah.

Several certification metrics are used to evaluate how high-performing the home design is, but there is no clear cut metric that can be used for our unique evaluation of what constitutes an "affordable" high performance home. All of these certifications whether holistic or concentrated on primarily energy savings do not even attempt to address affordability or how much it actually costs to get to these "levels" of high performance/ sustainability. I expose my students to the following energy saving certifications/ratings to familiarize them with potential options to evaluate future projects with:

- Residential Energy Services Network (HERS Rating)
- Passive Haus
- Energy Star for Homes
- Net Zero Ready Homes
- Architecture 2030 Challenge

I also expose my students to the following holistic certifications/ratings to familiarize themselves with potential options to evaluate future projects with:

- National Home Builders Associations National Green Building Standard
- LEED for Homes
- Living Building Challenge
- WELL Building Standard
- Green Globes

RESEARCH REVIEW AND METHODOLOGY

Energy modeling coupled with a simple return on investment (ROI) calculation is the research approach I have adopted, with concentration on those elements of the design that provide a lower true cost of home ownership that is affordable. This typically includes those design decisions that affect energy costs and maintenance such as building envelope products and MEP systems.

Research Method

In order to evaluate if design strategies we explored were affordable, a financial analysis of how much home an owner could afford was calculated. The first factor considered was the gross annual household income. The median gross income of our applicants is $35,280. HFH uses a maximum 30% housing expense ratio which includes the Mortgage, Property Taxes, Insurance, and Utilities. This equates to $882 maximum for all four of these housing costs in order for it to be considered affordable. Using historical data from comparable homes, the following monthly costs are assumed; Property taxes = $78, Insurance = $46, Utilities = $230 ($70 Electric Bill, $70 Gas Bill, $90 Water/Sewer/Garbage Bill). This requires the mortgage to be $528 or less. (Mortgage – Property Taxes – Insurance – Utilities) This also provides the maximum value of the home at $190,080 ($528 x 360 Months). These metrics provided the parameters that all design decisions were required to be evaluated against.

A simple return on investment calculation was established to quantify if improvements would be implemented. Because HFH sells the homes at no interest, the return on investment just had to be greater than $2.78 per month for every $1,000 spent in upgrades. ($1,000/360 months = $2.78) Those products or systems that provide a higher return on investment are more likely to be implemented within reason. The last 2 homes constructed both appraised at approximately $170,000.

RESEARCH RESULTS

Some of the easiest decisions to make were those that affected the building envelope of the home. Net Zero Ready guidelines and Passive Haus standards were used to establish how far above code minimums insulation levels should be upgraded and how tight of an envelope we attempted to provide. The symbiotic relationship of prescriptive insulation levels can at times dictate what wall assembly is selected. This was not the case in our home due to the fact that our primary goal was to eliminate all thermal bridges to the exterior of the home due to our cold climate. Heat loss was the primary factor that led to the design of our exterior wall system that was constructed with 2x4 studs at 16” on center, 7/16” oriented strand board, house wrap with taped seams, 1 ½” of expanded polystyrene (EPS) continuous insulation (R7.5), and vinyl siding. The use of EPS insulation was the only practice that was not a common practice that we needed to account for in our financial analysis of affordability. In our Climate zone 5A, exterior walls are required to have R20 cavity or R13 cavity + R5 continuous insulation. We chose to go with R15 blown in fiberglass insulation at a cost of $409 above the base price for R13 batts to ensure a more consistent installation quality. We also chose to upgrade the attic insulation from the code required R38 to R49 at a cost of $302 above the base cost. The air-sealing option we chose to invest in was foam sealing all stud cavities at a cost of $150 for the entire home. This

included using a foam gun to run a bead of expanding foam around each stud cavity, at the sill plate connection to the slab, and all penetrations through the top plates in the entire home. We also chose to upgrade the exterior continuous insulation from the prescriptive R5 to an R7.5 at the same cost of R5 due to our ability to negotiate bulk pricing and using EPS vs XPS. The total cost for upgrading our insulation was $861 which required a minimum ROI of $2.39. (861/360) The estimated ROI of energy savings due to this investment was above $10 per month, so these options were considered very affordable.

One upgrade that was a little harder to evaluate was the windows. The prescriptive code requirements for our climate zone is a U-factor of .32 or less. The base price for a double pane window package meeting this requirement was $2,125. The upgrade option to go to a U-factor of .27-.30 with low-e 366 glass filled with argon was an additional $325. This would bring the minimum ROI per month for this upgrade to $.90. (325/360) A 3% improvement in insulation values for the windows would equate to approximately $1.05 of ROI. Therefore this upgrade was considered a moderately affordable investment. To upgrade the windows to a triple pane system with a U-factor to .22 would have cost $1250 above the base price. The minimum ROI per month of this upgrade would need to be $3.48. (1250/360) A 10% improvement in insulation values for the windows would equate to approximately $3.50 of ROI. Therefore this upgrade was considered a risky investment and was ultimately not selected. Increasing the cost of the home by $1250 was not worth the risk associated with the windows performing as modeled to only produce $.02 of ROI monthly.

A major design change from the traditional method of construction was to construct the home on an insulated shallow foundation. This allowed a monolithic thickened slab to be poured inside of a 4” EPS insulation exterior edge formwork and atop 6” of EPS at the thickened slab portion and 14” under the remaining slab. Energy modeling using RemRate showed that this insulation equated to 9 HERS points or approximately 9% of our annual energy efficiency. The greatest benefits of this design allowed us to eliminate 25% of our typical foundation costs to get below the frost level of 30” in our climate by removing the need to have footings poured with 2’-6” stem walls poured atop the footings. There were lower excavation costs associated with this design, but increased infill gravel to meet compaction requirements. This design also eliminates any concern of Radon intrusion into the home because of the minimal depth of excavation and the secondary sealed gravel bed and penetrations using 6 mil plastic just below the slab. These savings equated to $7,300. The cost of the insulation was $5,443.42 and the additional gravel to accommodate this type of insulation was an additional $500 bringing the net savings of insulating our entire foundation and slab edge with R19.2, under slab insulation to R 67, and under thickened slab footings to R28.8. The ROI of this option is exponentially positive because of the cost savings over the traditional method for slab on grade construction in our climate. Estimated ROI for this method of construction is in the $7.56 per month range. (60% of $140/ month HVAC x 9% of Heat Loss)

All indications from energy analysis point to our investments producing moderate to exponential energy savings. That was until it was discovered that there was not enough room in the utility closet for the furnace and water heater due to plumbing pipes being located in the center of the room. Initially, we thought that simply moving the furnace into the attic inside of the trusses would solve the problem. We framed out a large storage space and insulated it as

if it were going to be a part of the building envelope. The negative was that this required that the duct runs be insulated as they ran through unconditioned space in the attic. Because the utility room was meant to be inside the buildable footprint, it was not isolated from the rest of the home. The HVAC system was an area that little to no investment was made due to the thinking that the home was super insulated and would require a smaller system to maintain a comfortable environment. The furnace was upgraded to a single stage 95.5 AFUE gas fired appliance at a cost of $550, and the AC unit was not upgraded past the 13 SEER code required minimum. A damper set up to act like an HRV with the required thermostat was selected at a cost of $250. The ROI was nearly impossible to calculate using energy modeling, so the assumption used was that we would see a 5.5% increase in gas efficiency. This would equate to our minimum required ROI for this system to be $2.22 per month. ($800/360) The estimated ROI is $3.85 ($70 * 5.5%) which would make this moderately affordable.

The water heater was not upgraded and a .62 EF 40 gallon gas fired water heater was installed. This proved to be our biggest mistake that coupled with the moving of the furnace into a make shift conditioned space was our nemesis. The water heater required that an 8" combustion air intake be installed into the utility room. This room was not thermally isolated from the rest of the home with an exterior door and insulation. According to Energy Star, air sealing can account for 20% of heating and cooling costs. When we started the blower door test, it was quickly identified that this was a large oversight on our part. We had attic insulation back drafting into this room from the attic because it was not dry-walled. The HERS rating as tested would have given us a HERS rating of 75. The blower door produced 1800 cfm or 10.6 air changes per hour (ACH) which is well above the Utah code limit of less than or equal to 5 ACH. The duct blaster was equally disheartening with 375 cfm or 29.5% total leakage. 24.5% was leaking to the outside. Utah code requires 8% or less dust leakage and does not have any leakage to the outside requirements. We were hoping to hit the Energy Star limits of 4 ACH, Total Duct leakage of 8 ACH, and leakage to the outside of less than 4%. We taped off the door to the utility room and ran the blower door test again. This would have resulted in a HERS rating of 71 as the leakage was 1100 cfm which equated to 6.5 ACH. We discovered that our home was leaking at almost all penetrations through the ceiling and our investment in foam sealing all cavities just enhanced our leaks at the sill plate and through the attic. We identified leaks in our sliding glass windows and at almost all interior outlets and light switches. The largest leaks were through our bath fans. It was eye opening how our attempts to make a tight well insulated home were compromised by lots of little air leaks to our unconditioned attic space.

A quick inspection of the ductwork identified that the workmanship of connections to the main trunk line were unacceptable. No mastic or duct tape was used on the taps to the main trunk line in the insulated furnace room loft. There were also many holes identified that were thought to have been filled by the insulator. A large effort was made to correctly tape and mastic all connections, install an OSB ceiling in the utility room, insulate the walls of the utility room, install an exterior door to better isolate the utility room thermally and air seal it more effectively. All penetrations in the ceiling and walls were caulked as well as the sill plate where air leakage was detected. We plan to test this home again and see what the net impact each of these changes had on our air tightness. One major example that highlights where conventional high performance options are not selected would be in not including a solar array to offset 100% of the annual energy consumption. We have not been able to get a solar array to pencil

because it has the highest initial cost that would preclude most of our owners' ability to afford the mortgage. The last home we constructed was appraised at approximately $170,000. The approximate cost of a solar array to take the home to net-zero energy would have cost approximately $25,000. (5 KW system @ $5 Watt) This would require that our energy bill be lower than $69.50 (25 x $2.78) for this to have a positive ROI. Although it would provide a minimal ROI, it would increase the mortgage beyond the affordability requirements of housing cost ratios set by HFH. Our home price would be raised to $195,000. (Assuming the appraisal included the total cost of the solar array) This puts us approximately $5,000 above the affordable limit for our typical homeowner.

DISCUSSION

We were hoping to have a HERS rating in the 50's. Even if we were able to get the air leakage to 800 cfm or 4.7 ACH with 100 cfm or 7.9% duct leakage and only 3.9% to the outside attic our HERS would have been 64. We feel confident we have made the adjustments necessary to achieve these air and duct leakage metrics identified through Energy Star as quantifying a tight high performance home. Although energy bills are significantly lower than comparable homes HFH has constructed in the past, we feel like we can push this even further and achieve our goal of building "Affordable High Performance" homes that will provide a lower true cost of ownership. It is vital to concentrate on not only providing a tight, super insulated, and well ventilated home, but also the quality of workmanship that is installing these technologies. Working with primarily a volunteer workforce has proven to be more challenging that we anticipated. Doing your best work does not equate to quality if you do not know what it is supposed to look like when you are done. We have seen that there are some job functions that need to be done by experienced craftsman like installing exterior doors and windows, and finish work. We have a renewed vigor to hold our subcontractors accountable for the workmanship of their systems and how they integrate into our high performance goals. Although there is no universal definition of what constitutes a "high-performance home", we feel we are setting our own higher bar for "comfort, durability, indoor air quality, and lower energy use" as well as "energy efficiency, sustainability, and the use of environmentally friendly products".

Thermal imaging proved that we did a great job significantly reducing thermal bridging to the exterior of the home. We maximized our greatest solar orientation and provided a comfortable home for a well deserving family who are grateful to be in a home they can afford to live in and maintain. We learned a lot of about the synergies of a tight, super-insulated home. The greatest take away for us is that we have established a simple yet reliable method to evaluate high performance upgrades with. Our current home in permitting will be an all-electric home with a HERS rating of 43 and could be a net zero home with a 3.5 KW solar array. Without this home as a reference point, we would not have been able to implement the things we learned doing this project on that home. Technologies that we have included in that home as a direct result of lessons learned on this home include; using a liquid applied air/water barrier on the exterior of the OSB, increasing the insulation levels to R31 by adding 2" of continuous rigid XPS (R10) exterior insulation and using 2x6 @ 24" o.c. advanced framing to allow R21 blown in fiberglass in the cavities, using AeroBarrier at 4 way stage to air seal the home to an ACH of less than 1, and finally ensuring that all HVAC is within the thermal envelope of the home. It is critical that Energy Modeling be completed during the schematic design phase using BeOpt to identify

the most cost optimal envelope and systems. These options can be verified using RemRate to provide an estimated HERS rating that will also help you quantify realistic energy costs.

CONCLUSION

High performance metrics exist through Passive Haus, Energy Star, and Zero Energy Homes that will provide the baseline for how the home should perform energy efficiently. The missing element is to provide some metric to evaluate if the high performance home is affordable. Any home can be considered high-performance if you throw enough money at insulating it well, air sealing it, and providing healthy levels of ventilation. Using a simplified net present value of return on investment provided HFH a way to make decisions on what would provide a high-performance home that was still affordable to our low income population. Without knowing what an affordable monthly payment is for the homeowner in the beginning, it is impossible to design and construct an "Affordable High-Performance Home". A true cost of ownership must be established to take into account the mortgage, insurance, and utility costs. Using Federal guidelines (30% Household Income), you can identify what the maximum mortgage can be which in turn controls what your total construction costs can be.

Once you have identified what your total construction costs can be, you need to establish a baseline budget for the home to evaluate return on investments against. You will need to be able to identify how much specific elements such as insulation, windows, air sealing, HVAC systems, appliances, etc. will cost to upgrade. The calculations for HFH are much simpler because they do not include interest. However a quick online mortgage calculator can tell you what a specific amount of money will cost you per month which provides the minimum ROI to break even with that upgrade. For example, a $1500 upgrade will cost you $7/ month at a 4% APR interest rate. For HFH we determined that as long as this upgrade cost did not push the total construction costs past the affordable hard limit we would entertain if it provided an affordable ($.25-$1.00/ month) ROI. Those ROI's that were below $.25/ month were considered risky due to energy modeling not being able to take into account installation errors or omissions and quality issues due to a volunteer labor pool. Those items that provided a $1.00 + / month ROI were considered very affordable.

Further research needs to be done to tie a financial amount to each HERS point. This can be simulated using BeOpt and RemRate, but there are so many variables and using database national averages can only get you so close. Although it is not a perfect method to quantify what is considered affordable, it has helped HFH evaluate upgrade decision in their quest to providing decent, affordable housing for low income families.

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THE VALUE OF FEEDBACK COLLECTION PROCEDURES, TENANT ENGAGEMENT AND COMMUNICATION METHODS AND THEIR ROLE IN REFURBISHMENT AND NEW CONSTRUCTION IN THE SOCIAL HOUSING SECTOR

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Keywords: Feedback collection, communication methods, construction, social housing

Abstract

Since the 1960s, research on building performance has proved the value of continuous evaluation of the buildings that we use. Recently, the significance of the use of Post Occupancy Evaluation and Building Performance Evaluation methods has been highlighted by the reintroduction of Stage 7 at the Royal Institute of British Architects Plan of Work 2013 and the use of GSL Government Soft Landings by the UK Government for all public contracts. Additionally, research on the value of user feedback has resulted to the commercial use of BUS occupant survey methodology and DQM Design Quality Method. Even though these methods have proven their benefit to the built environment, research has been focused on the performance of office buildings. The housing sector has been largely ignored due to its fragmentation and complexity of the factors that affect it. The social housing sector, though, takes up to 17% of the total built environment of the UK. It has, therefore, a significant impact on CO2 emissions and living conditions in the country. The paper describes the findings of research on the procedures social housing providers use to communicate with their tenants and request feedback for their buildings. It also investigates the role of this information in the decision making process for refurbishment and/or new social housing projects. The research aims to create an understanding on the specific feedback needs of the social housing sector. Its ultimate purpose is to contribute to the design of an evaluation survey focused specifically in this sector.

INTRODUCTION

The value of feedback collection from our buildings has been under research since the 1960s. Early research in the sector (Manning, 1965; Markus et al., 1972; Ryn & Silverstein, 1967) has presented the difficulties and benefits of collecting information from buildings. Throughout these years, different types of buildings have been examined, especially during the 1970s (Friedmann et al., 1978). Since then, the research that resulted to the Building Use Studies (BUS) methodology focused on office and other public buildings (Leaman, 1995; Wilson, 1987). Domestic buildings have been left outside the priorities of research (Leaman et al., 2010) possibly because of their complexity. Apart from the technical design and construction of the building envelope, the most complex variable are the occupants. Extensive research in occupant behaviour (Langevin et al., 2015; Seryak & Kissock, 2003; Stevenson & Leaman, 2010) has led to the design of occupancy simulation models that are used to create some

understanding of this complexity (Bourgeois, 2005; Clarke, 2001; Fabi et al., 2011; Hong et al., 2015). Apart from the occupancy factor, the housing sector is fragmented due to different scales of ownership. The social housing sector, though, includes 17% of the total housing stock in the UK (DCLG, 2015), it is managed by a finite number of providers (Homes and Communities Agency, 2017) and has the ability to spearhead the introduction of in-use feedback collection methodology into the housing sector.

This paper is intended to present the method and preliminary results of the primary data research that is being conducted as part of a PhD research project.

Aim of primary data collection

The aim of the research is to create an understanding of Social Housing (SH) providers' operations in the following themes:

- Types of information currently collected by SH providers. Throughout the history of Post-
Occupancy evaluations different studies have sought different types of information: the PROBE studies looked into energy consumption and occupant opinion on environmental factors (Cohen et al., 2001), other studies looked into space design and configuration (Ryn & Silverstein, 1967) while others looked into the occupants' use of spaces (Friedmann et al., 1978), windows, lighting, blinds, fans and heaters (Nicol, 2001). The information obtained from this theme will indicate the value of the tenant feedback to the organisation. It will show if there is a specified method of obtaining feedback or it is just a generic complaint collection system.
- What use is made of this information within the SH providers' governance as far as decisions for maintenance and refurbishment are concerned. This theme aims to collect information on the communication filing processes of the organisation and if this information is revisited to create an overall understanding of the condition of the stock. The more convenient the system the easier the information would be used for refurbishment. A prominent example for the effective processing of building data, both qualitative and quantitative, is the use of Building Information Modelling applications (Bordass & Leaman, 2013; Ozturk et al., 2012)
- Types of information required but not collected by SH providers. This information will show if the organisation is processing the complaints or feedback in order to create an understanding of the overall performance of its stock. Most of the literature concerning Post-Occupancy Evaluations agree that there can be no useful evaluation of a building unless there is a body of performance data for it (Bordass, 2003; Cohen et al., 2001; Leaman et al., 2010; Preiser et al., 2015; Preiser & Vischer, 2005)
- Possible patterns that emerge due to size of SH provider, size of portfolio, provided services and any other characteristic.
- Third-party entities that affect the decisions and policies of SH providers and in what way.
- Existing knowledge and practice of Post-Occupancy Evaluation (POE) methodology and impact in operations. This theme aims to create an understanding on the actual knowledge of POEs and their use. Relevant examples of academic POEs in social housing have been published

from Pretlove (2016), Stevenson (2004) and Sodagar (2016). Other studies used POE to validate the usefulness of energy efficient technologies in buildings (Marsh, 2010).

Purpose of primary data collection

The outcomes of this research will be analysed in conjunction with existing POE research and practices, aimed for other sectors in the built environment. This process will identify the parts where the existing POE methodology could be amended to fit the specific requirements of the SH sector. The design of a POE method aimed specifically for the SH sector would expand the practice of POEs, assist SH providers to take more informed decisions for repairs and refurbishment of their housing stock, enhance the efficiency of the existing budgets and help towards the creation of a more financially and environmentally sustainable SH sector.

RESEARCH METHOD

The necessary primary data for the purposes of this research are being collected with interviews of the relevant executive officers of SH providers, consultancies, professional bodies, architectural practices and other relevant entities. The interviews are designed semistructured in order to leave the interviewee the appropriate space to analyse the specific situation and needs of each respective organisation.

Research process

Initial preparation and programming

The initial decisions for the characteristics of this research were based on extensive research of the existing literature, focused mainly on the current practices of POE in different sectors of the built environment. The decision to focus on the SH sector was based on the conclusion that the practice of POE in the sector has been historically limited. At the same time, the impact of the expansion of POE practice in the sector would be significant.

Main participants pool

The principal pool of participants for the purposes of this research is the Government's list of registered SH providers. This list was first published on the official Government's website on the 11th of February 2013 and since then it is frequently updated. Due to the frequency of updates, it was decided that the version of the list that would be used for this research is the one published on the 1st of December 2016. The list is provided freely from the website and includes the following information in a spreadsheet form:

- Name of registered provider
- Registered Provider Code
- Postal address and postcode
- Phone number
- Designation (for-profit, non-profit, local authority)
- Date of register
- Legal entity (charity, company, etc.)

This information was considered sufficient for the initial research on the providers. Web searches were conducted based on the information in the spreadsheet and further contact details were collected for the providers, including email addresses.

Geographic limitation

The total number of registered SH providers that were included in the official list was 1756. Due to the peculiar size and population density of the London area, it was decided to avoid including it to the sample. This left a total sum of providers in England outside of London to 1406, number which will be considered for defining the outcomes of the research.

In order to keep to the time and financial constraints of this PhD research, it was initially assumed that the wider Yorkshire area would provide an acceptable sample of the current situation in England. Based on the Government's list of SH providers, there are 20 providers in the Leeds postcode areas, 53 in the West Yorkshire area (Leeds, Bradford, Halifax, Huddersfield, Wakefield postcodes) and 124 in the Yorkshire and Humber area (West Yorkshire, York, Harrogate, Sheffield, Hull, Doncaster). The above numbers are respectively 1.42% for Leeds, 3.77% for West Yorkshire and 8.82% for Yorkshire and Humber.

Interview topics and approach

The data topics that would be targeted in the interviews were selected after analysis of the literature that took into consideration historical, social, political and organisational information relevant to the SH sector.

The questions that derive from the themes presented at the aims section have been arranged for a semi structured interview that would last for around 50-70 minutes. The reasons for this are analysed below.

- The usual business meetings last for about an hour. This way the interview could fit easily in an everyday schedule without much hesitation.
- The interviewee would need around 15-20 minutes to get accustomed to the interviewer. This is the main reason the interview starts with facts about the organisation that the interviewee is familiar with and then it moves on to subjects that might need more analysis. It is understood that that the interviewee is talking to a stranger about possible sensitive corporate matters and so the interviewer aims to avoid putting pressure towards subjects that the interviewee seems reluctant to answer. It is also understood from analysis of literature that actual practice of POE is very limited. Therefore, the fact that the interviewee is asked if they are practicing procedures that they most likely are not, places them in a defensive position. The interview is designed in such a way that the interviewee is asked to describe the procedures that take place in their organisation. By understanding that the questions are asked in a non-judgemental manner, the interviewee calms down and describe what they do. The interviewer aims to grasp chances and drive the interviewee to expand on the subjects that are important to the research.
- It is understood that the interviewee would be discussing their everyday job and that it might be tiresome to talk for more than an hour. The participants are understood to be volunteers and they are valued for their time. The discussion is approached in an informal manner so that the participants would feel positive and open up to the interviewer. The

profession of the interviewer is made known from the outset so that the interviewees understand that they are talking with somebody with relevant knowledge and experience.

- All the participants are warmly thanked for their participation after the completion of the interview. They are also greeted and thanked with an email the next day of the interview.

Contact method

It is understood that the vast majority of the SH providers have an active web presence. Most of the time, their actual operations are largely based on online communication tools that they provide to their customers. A web search of the name of the organisation provides easily its website most of the times. If it does not, it will provide some hint of its existence and further research will be conducted. The organisations that have an active website, present their contact details in separate web pages, while some provide separate routes of communication for their customers and general queries. Some organisations do not provide an email address but provide an online form that can be easily completed. In that case, they respond with an automatic acknowledgement email. The organisations are initially approached via email. As the organisations have an administrative team that receives the general enquiries, the initial email is addressed to the organisation team. It continues to present the subject of the research in two sentences so that the person that first reads it understands the general idea of the query. The text continues immediately with the request for an interview so that the reader takes action and forwards the query to the appropriate officer of the organisation.

The text reads as follows:

> *Subject: University research request*
>
> *Dear "provider" team,*
>
> *As part of my PhD research at Leeds Beckett University, I am investigating the procedures social housing providers use to communicate with their tenants and request feedback for their buildings. I am also looking into the role of this information in the decision-making process for refurbishment or new-built projects.*
>
> *I am contacting you to ask you if it would be possible to arrange for an interview with the relevant staff of your organisation, preferably Mr X or Ms Y, that will take no more than an hour in order to ask you some questions on the above subject.*
>
> *Kind regards,*
>
> *"Researcher"*

An example of the most usual response this email receives reads as follows:

> *Dear "Researcher"*
>
> *Thank you for contacting "our organisation".*
>
> *Your request has been forwarded to our Growth and Business Development Department "(or similar)"*
>
> *Regards,*

Customer Services

This email is sometimes followed by correspondence from a relevant executive senior member that either requests more information or simply begins the process of arranging for an appointment. When more information is requested by the possible interviewee, then an email is sent that presents the general themes of the interview. The response is kept concise so that too much preparation is avoided and the discussion can remain open to expand to possible relevant subjects that have not been thought of. An example email reads as follows: *Hi "executive officer" our discussion will concern the following subjects:*

> *-General information about the organisation e.g. age, size, ownership, managed properties number, structure etc.*
>
> *-Refurbishment and maintenance policies e.g. budget, funding, standards, cycles, organisation, decision making processes etc.*
>
> *-Communication with tenants e.g. methods, type of information collected, use of this information, novel communications projects etc.*
>
> *If there is any other information that you would like please let me know.*
>
> *Kind regards,*
>
> *"Researcher"*

In the case that no response is received to the initial email, a second email is sent in order to remind of the initial query after 3 weeks. If this email receives no response, a phone call is made after 3 weeks to verify the unwillingness to participate.

Participation

So far, all the 124 SH providers in the Yorkshire and Humber area have been contacted using the approach method described above. From them, only 4 successful interviews have been conducted with SH providers. This counts for 3.22% participation rate. This rate is worryingly low and calls for more research into the reasons why this large number ignores participation into a university research project. Further research into the business condition of the SH providers showed that several have merged, others exist only on paper with the contact details pointing to an accountant and others are extremely small, with the number of properties they manage not being over 10. Further research into the subject is assumed that would bring forward financial, tax, business, cultural, social and political reasons. In any case, the exact numbers and situations are difficult to pinpoint without deeper and exceed the scope of this research.

Expansion of participants' pool

The low participation rate could seriously jeopardise the whole research, which would not be able to substantiate any results and outcomes. For this reason, the research had to widen its spectrum of respondents. Further attempts to approach other SH providers need to be based on the innovative character of the organisation. SH providers that have already taken part in research projects, be them academic or professional, have the potential to be more willing to participate in this research.

Further informal discussions on the subject were conducted with the representatives of the organisations that had already participated in the study. In addition to that, research was conducted on printed and online magazines for the sector. The main outcome of this research was the understanding of the existence of a network of entities that play a very important role to the practices of the SH providers. As a result of this research, the following entities were pinpointed as the most influential in the SH sector:

- Professional bodies play a very important role in defining the policies on which SH providers provide their services. Sometimes they provide professional development courses in addition to their advisory role. The most impactful in the UK are:
  - The Chartered Institute of Housing ○ The National Housing Federation
  - The Royal Institute of British Architects Housing Group ○ The National Energy Action
- Academic courses on housing that cultivate a large number of professionals who end up working in the sector. The CIH recognises the following BA(Hons), BSc(Hons) courses at the below universities in the UK: ○ Leeds Beckett University ○ London South Bank University ○ Cardiff Metropolitan University ○ De Montfort University ○ London Metropolitan University ○ University of the West of England, Bristol ○ Glyndwr University
- Architectural practices that design SH work together with SH providers and use their feedback in order to provide better services. They sometimes add to the process by requesting further information from the occupants.
- Private consultancy practices that advise SH providers on policy, strategy and practice. They also provide professional development courses. Their impact value is on the fact that instead of single SH providers, these organisations have collected experience from all their clients.
- SH residents lobbying groups. Their impact is important as they are the voice of SH residents. The ways they aim to communicate with SH providers could be an important input to the research.
- The UK Government through the introduction of legislation and funding. Since the mid2000s, the Government's policies on housing have changed radically, from focusing on and funding environmentally sustainable housing and standardising housing conditions to section 106 and demanding VAT for SH development. Example legislation that will be analysed includes:
  - The Decent Homes standard ○ The Code for sustainable homes ○ The regulatory standards for SH providers

The expansion of the spectrum of participants would not have any general effects, neither to the aims of this research, nor to the outcomes. The approach that was decided as far as the interviews are concerned changed mainly from "What are your practices on…" to "What do you advise your clients to do on…"

OUTCOMES OF RESEARCH PILOT

As of the writing of this report, in addition to the 4 SH providers that have participated in this research, 2 private consultancy practices have also been interviewed. In general, these initial interviews, together with the effort to arrange for them have given some preliminary insights on the condition of the sector, the current practices on feedback collection, their needs in terms of information and the impact of the residents in their practices.

- **History**: 3 out of the 4 participating SH providers have resulted out of mergers of historical providers that have happened during the past 10 years. This has caused significant problems in the organisations in terms of IT systems compatibility, governance structure, housing stock standards, internal communications, communications with their tenants and scattering of the housing stock. This was the result of two major Government policy changes in the sector, mainly financial: the abrupt interruption of funding on sustainable housing development and the cap in the social rent. As these were the main sources of income, the SH providers have been forced to resort to multiple measures to survive: merging of providers, the development of housing to sell at market value, renting of stock at market rents and extensive borrowing, minimisation of staff, hiring of in-house maintenance teams.
- **Services provided**: The services the organisations provide extend far beyond the development and management of their stock. Their social focus requires them to provide financial and social assistance services to their tenants, actions that stretch their budgets even further. The positive outcome of these services is the more extensive communication with the tenants, during which, more feedback on the stock can be collected.
- **Main issues faced**: The main problems that the organisations face have not shown any significant patterns yet. Depending on the position of the interviewee in the organisation, different problems are presented as responses. One common issue that the participants agree on is the lack of knowledge of basic lifestyle principles that their tenants have, despite repeated attempts and multiple methods used to educate them. Depending on the size of the provider, issues that have been mentioned include governance response times, high maintenance costs and building design on new developments. The consultancies that were interviewed referred also to subjects as health and safety compliance and the delivery of quality in new-built housing.
- **New-built development**: Half of the providers interviewed responded that they do not develop new housing due to lack of funding and the extensive cost of borrowing. All of them, though, acquire new housing through “section 106”. Nevertheless, this adds to the lack of standardisation within the stock and, as an outcome, raised costs of maintenance. The consultancies in this case suggest the necessity of a sustainable mixed strategy that combines social and market prices so that the market assists to the provision of social housing.
- **Information collection, types and management methods**: All providers use professional asset management software to store and process information on their stock. The main information input source for all providers are the stock condition surveys. The large amount of properties, even in the smallest of providers, consists a huge and expensive undertaking, so the stock is surveyed every 4-10 years, depending on the amount of work the staff has. As the asset management applications are not combined with the customer services and complaints applications, the information of the two systems is rarely analysed. This fact is

also verified by one of the consultancies that were interviewed. The information collected by the providers is mainly quantitative and includes component data and installation/ maintenance times. The only tenant opinion information that is collected is fault reporting, satisfaction on repairs and complaints on services. All providers are required to conduct SAP and EPC surveys on their stock. This information is only used for statistical and publicity reasons. No information on energy consumption is collected from the buildings, except for pilot research projects that refer to a very small number of properties in specific schemes. Qualitative information from representatives of the tenants is discussed during community engagement events and workshops that take place once or twice a year. The tenants also have in all cases a representative person or group that takes part in governance meetings that has a say in multiple cases. In one case, the tenant representative group is allocated with a yearly budget of £50000 to invest in projects of its own choice. These funds usually go to landscaping, extreme situations and in specific cases useful additions to the buildings.

- **Requirements for specific types of information**: All the SH providers that were interviewed agreed that the information collected by the stock condition surveys was more than they could analyse and produce useful conclusions. In some cases, the duplication of information in similar properties, also known as "cloning", has resulted to problems in the management of specific groups of properties and, eventually, the need for repeating the survey for the specific property groups. This practice was also condemned by the consultancies that were interviewed. One subject that was discussed by all the participating SH providers was the collection of real life fuel consumption information. The majority of the providers agreed that understanding occupant consumption patterns would help them make more informed decisions in areas that span from building performance to occupant behaviour, lifestyle choices and sensitive issues to financial and fuel poverty. One provider moved further and mentioned the possibility of monitoring indoor air quality. The larger providers that participated in the study have pilot research projects that involve 10-20 properties each, where fuel consumption and occupant satisfaction information is collected in high specification or Passive House developments. The sustainability, though, of these projects is problematic because the resources needed for collection, analysis, reporting and use of this information in the governance process are not easily available to the providers. As a result, the programs are time limited to 1 or 2 years post completion.
- **Information and feedback collection methods**: All SH providers, irrespective of their sizes, reported that they depend on their surveyors, in-house or contractors, housing officers and service crews to collect feedback for their buildings. Building information is collected by surveyors that visit the properties during stock condition survey periods and between tenancies. Other building information is collected by repair crews that visit the properties after complaints. This information is mainly collected verbally, any issues are dealt with there and then and it is rarely analysed to provide insights. The main feedback that is collected concerns quality and speed for repair services and services provided by the organisation. This information is collected mostly via telephone surveys conducted by contracted third party companies. One SH provider conducts property satisfaction surveys on the first week and on the sixth month of each new tenancy and another on the first month of each new tenancy in a new-built or major refurbished property. In all interviewed organisations, the tenants had easy communication with the management via online forms, social media forums and telephone

hotlines. The tenants are also organised with representatives that communicate with the management 1-4 times per year. While the organisations were very happy with the input that they got from their communication with their tenants, the consultancies that were interviewed reported that rarely is this information useful to the management. This is because these groups mainly lobby for specific issues rather than debate ideas for general improvement.

- **Use of feedback in the decision-making process**: The information and feedback that is collected from the building stock is rarely analysed to a useful extent. Management staff frequently filter the importance of the information subjectively, before it is discussed in governance processes. While most of the participating organisations rarely feed this information to new-built and major refurbishment schemes, one participant organisation reported that they use feedback extensively. More specifically, they analyse component repairs information for patterns and review the "employer's requirements" annually. They also analyse stock condition information to inform "value engineering" decisions for new-built and major refurbishment projects. Even though the participating consultancies know the value and suggest the use of feedback in the decision-making processes, they understand the difficulties for implementing this and suggest policies changes for newbuilt developments.
- **Post-Occupancy Evaluation methodologies; knowledge and/or practice**: No knowledge of Building Performance Evaluation or Post-Occupancy Evaluation methodologies has been observed in the interviews so far, except for one consultancy. This consultancy had knowledge of the existence and value of these processes due to its involvement with academic research projects with the former Commission for Architecture and the Built Environment.

CONCLUSION

As this paper is part of an ongoing PhD research project, it is understood that the small sample of responses resulting from the limited willingness for participation from Social Housing providers and the limited financial ability to expand the research pool further than certain geographical extents have serious consequences on the validity of the presented results. Considering these limitations, the data collected so far shows that despite the serious financial problems the Social Housing sector faces, an established cultural and procedural substrate already exists for the collection of feedback from buildings in-use. These interviews have verified some of the outcomes of the literature analysis, especially the fact that the practice and knowledge of the existence of POE methods are far from the norm. The willingness and intuitive methods that some Social Housing providers use to collect the feedback they need from their tenants, shows that research in the subject needs to continue and innovative information methodologies need to be designed to bring the housing construction sector to the 21st century.

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THE ADOPTION OF WATER CONSERVATION MEASURES BY MIDDLE- AND UPPER-INCOME HOUSEHOLDS IN NELSON MANDELA BAY MUNICIPALITY IN SOUTH AFRICA

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Abstract

South Africa experienced prolonged droughts in recent years, and the growth in water usage outpaces the water supply in some major municipalities. Cape Town made recently international headlines as the first major city which could run out of water, but Cape Town is not the only municipality to run out of water. The Nelson Mandela Bay Municipality (NMBM) located on the south-eastern coast of South Africa also operates in a water-scares environment and has imposed water restrictions on their residents since August 2016. And as of January 2018, the NMBM is in a water emergency situation. This research examines the level of awareness of the NMBM households towards the drought crisis in the bay as well as their knowledge and implementation of water conservation measures in their homes and willingness to invest in water-saving installations. The research adopted the use of a selfadministered questionnaire which was distributed via four schools. Using descriptive statistics, a total of 202 datasets were analysed. This research report is based on a pilot study and is of exploratory nature. Considering that the residents of the Nelson Mandela Bay Municipality (NMBM) had one year to grasp the concept of water restrictions, more than one third (39.1%) of the respondents are "unsure" of their monthly water consumption. "Cost" and "unsure where to start" was named by 36.4% as barriers to installing water-efficient measures (WEM), but the "real" issue is the ignorance about their water usage. This research is the first of its kind in South Africa; therefore, the findings are very valuable as a starting point to address changing South Africans' attitude towards fresh water and by extension changing people's perception towards water worldwide. People must recognise that drinking water is turning into a commodity, a commodity that will soon split the world into countries that have and countries that have not enough fresh water.

INTRODUCTION

"Water, water everywhere, nor any drop to drink." While seawater is plentiful, people can only survive with fresh water is the quintessential of the Samuel Taylor Coleridge poem from the 17th hundreds. Boltz (2017) states that fresh water is scarce, but the most vital resource for life on Earth as we know it, and yet "despite its vital importance to humanity, the global water crisis has failed to take priority in the public consciousness". The importance of water and sanitation was officially recognised when in 2010 the United Nations declared "the right to safe

and clean drinking water and sanitation as a human right" (UN, 2010). The General Assembly of the United Nations ratified the decision by including "availability and sustainable management of water and sanitation for all" as one of its 17 sustainable development goals for the 2030 development agenda. Similarly, the World Economic Forum (2018) considers the "water crisis" as one of the top 5 global risks.

The World Health Organization (WHO) & United Nations Children's Fund (UNICEF) report that in 2015, 11.6% of the global population (844 million of 7.3 billion people) had no access to a basic drinking-water service and that 502 000 deaths each year were due to diseases transmitted by contaminated water (WHO & UNICEF, 2017). The same report states that climate change, increasing water scarcity, population growth, demographic changes and urbanisation already pose challenges for water supply systems now and that by 2025 as much as 50% of the world's population will be living in water-stressed regions. Diminishing water supplies result in food crises, social instability and large-scale migration additional to the spread of infectious disease (World Economic Forum, 2016). A study conducted in 2014 looked at 71 surface-water supplied cities across 39 countries with populations exceeding 750 000. Of these 71 cities, 25 (36%) were already considered to be in a vulnerable position due to their inability to meet the water demands by humans, agriculture and the environment (Bishop, 2016).

With the average global temperature to rise by as much as 6.4 °C (The World Bank, 2012) as well as the global population to increase from 1.5 to 6.1 billion people by the turn of the century (Roser & Ortiz-Ospina, 2017) the authors hypothesise that drinking water will be the “new gold” which will divide the world. Already now, one in seven people lacked access to clean drinking water globally (Bishop, 2016) with an even worse ratio on the African continent where one in three people do not have access to clean drinking water (WHO & UNICEF, 2017). This highlights the imminent threat the global population is facing. Plans and measures need to be put in place now, to ensure that the predictions made, will never become a reality.

South Africa was listed as one of the thirty driest countries in the world, with an annual average rainfall of 40% less than that of the rest (du Plessis, 2017). This is a severe problem as South Africa’s population is provided with freshwater through a network of surface-water catchment areas. High evaporation rates compromise the efficiency of water supply due to South Africa’s general warm to hot climate as well as its old and poorly maintained infrastructure. South Africa experienced prolonged droughts in recent years, and the growth in water usage outpaces the water supply in some major municipalities. South Africa’s rainfall is highly seasonal and unevenly distributed through the country’s provinces. Water plays an integral part in the human anatomy as well as it is essential for cities and economies. The South African agricultural sector is a conundrum. It is responsible for consuming approximately 60% of South Africa’s water for irrigation purposes (Department of Water and Sanitation (DWS), 2015), but it is also one of the primary contributors to the national economy. For this reason, South Africa will have to develop new techniques or alternative methods for the agricultural sectors’ irrigation needs. While the need for employment and food is essential for South Africa as a country, the government will be left with making tough decisions in the near future as to how the use of its limited water sources are prioritised. Cape Town made recently international headlines as the first major town which could run out of water, but the “mother city’s” predicament is not unique. The Nelson Mandela Bay Municipality (NMBM) located on the south-eastern coast of

South Africa also operates in a water-scares environment and has imposed water restrictions on their residents since the 31
August 2016. This was necessary after negations, pleads and gazetted notices from the Minister of Water and Sanitation to reduce water consumption by 15% (Lovemore, 2016). Water restrictions prohibited the use of municipal water for "unnecessary" activities amongst others watering gardens, topping up pools, ponds and fountains and using hosepipes for any activity. The mayor of NMBM urged its residents to use water sparingly and to restrict municipal water usage to less than 70l/ per day per person. And from the 1 December 2016 municipal water was charged at the higher "Part B Tariffs". Those restrictions were tightened when the dam levels which supply the municipality dropped below the 40% mark. On the 25 May 2017, the NMBM was declared a water emergency area and stricter measures were imposed. Water "wasting" domestic users were threatened with the installation of water flow restrictors if they were using more than 40 kl/month. Finally, in January 2018 the Nelson Mandela Bay Municipality had tightened the water emergency restrictions when dams dropped below 30% and as of the 26 July 2018, while making the final edits to this paper, the dams fell below 20% which meant a count-down to "day zero"− the day when taps run dry − began.

This study is the first of its kind at a unique point in time. The survey was conducted in August 2017, twelve (12) months after water restrictions were imposed on the NMBM residents. The study explored whether households in the Nelson Mandela Bay Municipality (NMBM) are firstly aware of their water consumption and secondly which water-reducing installations and behaviours they have implemented one year into water restrictions. Lastly, the study investigated the willingness of the NMBM residents to invest in water saving measures to reduce water consumption in the long-term. Those objectives would helped to understand how to drive sustainable water use. It is the current generation's responsibility to protect the finite resource of drinking water and to push "sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Report, 1987), by reduce, reuse and recycle water. The conservation of water is the best way to ensure that there will be enough water for everyone.

RESEARCH METHODOLOGY

The study focused on middle- and upper-income households located in the NMBM, since they comprised the majority of the households in Nelson Mandela Bay with a combined 57.7% (StatsSA, 2011) and deemed to possess the minimum financial means to implement water-efficient changes to their dwellings. The research adopted the use of a self-administered hardcopy questionnaire which was distributed via four "middle-class" schools in NMBM. It was established that based on the average household size as well as the average age of the population in the bay at least one household member must be a school-attending child. A total of 780 questionnaires were distributed, 335 were returned from which 213 surveys were sufficiently completed to be included in the analysis, resulting in a response rate of 27.3%.
The fact that the water crisis was so prevalent and a point of discussion in most classrooms made this part of the study a lot easier than initially anticipated. Two grades from any

participating school were selected randomly. The blank questionnaires with a cover letter in unsealed envelopes were then distributed and collected by the head teachers of every chosen grade. The cover letter briefly explained the purpose of the study as well as the structure of the questionnaire. The researchers asked the heads of the respective households to complete the survey and return it sealed in the provided envelope within a 10-day period. All the responses were captured in an excel spreadsheet. Once this was complete, an independent individual was asked to replicate this input process to check for mistakes. From the 213 completed questionnaires another 11 responses were discarded after outliner detection as to water usage; therefore 202 datasets were included in the analysis. The study was of explorative nature as a pilot study for further research. The response rate was not sufficient to make an inference to the whole household population of the Nelson Mandela Bay Municipality. The questionnaire consisted of six sections. Section A addressed the demographical information, section B established the awareness of the household's water consumption and section C covered the "water luxury" items households possess. Section D & E are not applicable to this paper, and section F covered the willingness of expenditure on watersaving installations. Three-quarters of the questions were on a "yes", "no" or "unsure" scale to simplify the questionnaire. The data obtained were analysed using descriptive statistics, and the results are presented in the next section of this paper.

RESEARCH RESULTS

The study aimed to explore whether households in the Nelson Mandela Bay Municipality (NMBM) are firstly aware of their water consumption and secondly which water-reducing installations and behaviours they have implemented. Lastly, the study investigated the willingness of the NMBM residents to invest in water saving measures to reduce water consumption in the long-term.

Table 1 shows the average water consumption per month per head by ownership of property. The majority (86.6%) of the sample are property owners, while only 13.4% rented. The household size is described in Table 3 with 48.0% consisting of households of four (4) people, following a normal distribution with two (2) people per erf being the lower boundary and more than six (6) people being the upper limit respectively.

Despite the fact that every metered home receives a monthly municipality statement which displays the monthly water consumption a scandalous 39.1% of the participating middle- and upper-income households were not able to name their monthly water consumption (Table 1). Only 9.9% of households consumed water sparingly and within the, at the time of the survey, requested amount of 70l per day per person, which equates to the "1-2kl" category. More than a half (37.1+13.9 = 51%) of the sample consumed water in excess to the requested target, and 1.5% of households (Table 2) used more than 40kl per month, which would have warranted an installation of a water flow restriction device. As per Table 1 people who rented are less aware of their water consumption than households which lived in their property.

Table 1: Average water consumption per month per head by ownership of property

	Average water usage per month per head				
Ownership	**Unsure**	**1-2kl**	**3-4kl**	**≥5kl**	**Sum**
Owner	30.7%	7.9%	35.6%	12.4%	**86.6%**
Tenant	8.4%	2.0%	1.5%	1.5%	**13.4%**
Sum	**39.1%**	**9.9%**	**37.1%**	**13.9%**	**100.0%**

Table 2: Water consumption per month per household

	Water usage per month				
	Unsure	**≤15kl**	**15-40kl**	**>40kl**	**Sum**
Participating households	39.1%	32.2%	27.2%	1.5%	**100.0%**

Table 3: Average water consumption per month per head by number of people (per erf)

	Average water usage per month per head				
Number of people (per erf)	**Unsure**	**1-2kl**	**3-4kl**	**≥5kl**	**Sum**
2	3.5%	-	2.0%	1.5%	**6.9%**
3	6.4%	1.5%	2.5%	1.0%	**11.4%**
4	16.8%	5.0%	20.8%	5.4%	**48.0%**
5	9.4%	1.0%	8.4%	5.0%	**23.8%**
≥6	3.0%	2.5%	3.5%	1.0%	**9.9%**
	39.1%	**9.9%**	**37.1%**	**13.9%**	**100.0%**

More than half (56.4%) of the surveyed households make use of an alternative water source from which 38.6% use one (1) alternative water source and 17.8% (16.8+1%) make use of multiple alternative water sources (Table 4). Households with alternative water sources are more aware of their water consumption which is indicated by the "unsure" responses.

Rainwater harvesting is the first choice of alternative water sources with 34.2%, followed by greywater recycling with 14.22% and borehole water with 8.0% (Table 5). However, not even one household is implementing blackwater recycling. Table 5 indicates that households usually do not use a combination of rainwater harvesting (25.7% vs 8.2%) and boreholes (6.9% vs 0.7%), but greywater recycling is the "first choice" when more than one alternative water resource is used.

Table 4: Average water consumption per month per head by number of water sources

	Average water usage per month per head				
Source of water supply	**Unsure**	**1-2kl**	**3-4kl**	**≥5kl**	**Sum**
Municipality only	20.8%	5.0%	11.9%	5.9%	**43.6%**
Municipality & alternative water source	18.3%	5.0%	25.2%	7.9%	**56.4%**
Sum	**39.1%**	**9.9%**	**37.1%**	**13.9%**	**100.0%**
One (1) alternative water source	13.4%	2.5%	16.3%	6.4%	**38.6%**
Two (2) alternative water sources	5.0%	2.5%	7.9%	1.5%	**16.8%**
Three (3) alternative water sources	-	-	1.0%	-	**1.0%**
					56.4%

Table 5: Source of alternative water supply

	Number of alternative water sources			
Source of alternative water supply	**One (1)**	**Two (2)**	**Three (3)**	**Sum**
Borehole	6.9%	0.7%	0.3%	**8.0%**
Blackwater recycling	-	-	-	**-**
Greywater recycling	5.9%	7.9%	0.3%	**14.2%**
Rainwater harvesting	25.7%	8.2%	0.3%	**34.2%**
Sum	**38.6%**	**16.8%**	**1.0%**	**56.4%**

Table 6 shows that a blatant 38.1% of the participating households have no water-efficient measures (WEM) installed. Almost two third (61.9%) of the sample data have at least one (1) WEM installed with 28.7% (20.8%+7.9%) using two or more water-efficient measures (WEM). Water-efficient showerheads lead the water-efficient installations with 45.2% followed closely by dual flush toilets (42.2%) and at the very bottom water-efficient taps with 12.6% (Table 7).

Table 6: Average water consumption per month per head by water-efficient measures (WEM)

	Average water usage per month per head				
Water-efficient measure (WEM)	**Unsure**	**1-2kL**	**3-4kL**	**≥5kL**	**Sum**
None	16.8%	3.0%	11.9%	6.4%	**38.1%**
One or more WEM	22.3%	6.9%	25.2%	7.4%	**61.9%**

Sum	**39.1%**	**9.9%**	**37.1%**	**13.9%**	**100.0%**
One (1) WEM	13.9%	3.0%	12.4%	4.0%	**33.2%**
Two (2) WEM	5.9%	3.0%	10.4%	1.5%	**20.8%**
Three (3) WEM	2.5%	1.0%	2.5%	2.0%	**7.9%**
					61.9%

Table 7: Average water consumption per month per head by water-efficient measures (WEM)

	Average water usage per month per head				
Water-efficient measure (WEM)	**Unsure**	**1-2kL**	**3-4kL**	**≥5kL**	**Sum**
Dual flush toilets	12.1%	5.0%	20.1%	5.0%	**42.2%**
Water-efficient showerheads	16.1%	5.0%	18.6%	5.5%	**45.2%**
Water-efficient taps	5.5%	2.0%	2.5%	2.5%	**12.6%**
					100.0%

Table 8 shows that the top two barriers for WEM installations are on par. Namely “cost” and “unsure where to start” share the top position with 36.4%, followed by “lack of time” with 15.6%. From the 9.1% of households who indicated “other” in the table below, more than two thirds (6.5%) did not implement any water-saving installations since they were renting.

Table 8: Average water consumption per month per head by reasons for “without WEM”

	Average water usage per month per head				
Reasons for "without WEM"	**Unsure**	**1-2kL**	**3-4kL**	**≥5kL**	**Sum**
Cost	13.0%	1.3%	16.9%	5.2%	**36.4%**
Unsure where to start	15.6%	1.3%	9.1%	10.4%	**36.4%**
Lack of time	7.8%	1.3%	6.5%	0.0%	**15.6%**
Unsure who to contact	3.9%	1.3%	3.9%	2.6%	**11.7%**
Other	5.2%	1.3%	1.3%	1.3%	**9.1%**
					100.0%

The results from Table 9 are promising, 23.8% of respondents are willing to invest more than 4500ZAR, followed by 66.3% prepared to spend between 500-4500ZAR (≈ 30-270€). Only 9.4% are not willing to invest anything more than 500ZAR. One would expect that the majority of

those households are renting, but that is not the case. A surprising 7.9% property owners are only willing to invest less than 500ZAR (≈ 30€). On the other end of the spectrum, as expected, property owners comprise the majority of households which are prepared to make a significant investment of more than 4500ZAR (Table 10).

Table 9: Average water consumption per month per head by investment in WEM

	Average water usage per month per head				
Amount prepared to invest for WEM	**Unsure**	**1-2kL**	**3-4kL**	**≥5kL**	**Sum**
Unsure	0.5%	-%	-	-%	**0.5%**
Minor (<500ZAR; ≈ 30€)	5.0%	1.0%	2.5%	1.0%	**9.4%**
Medium (500-4500ZAR)	26.7%	7.4%	23.8%	8.4%	**66.3%**
Major (>4500ZAR; ≈ 270€)	6.9%	1.5%	10.9%	4.5%	**23.8%**
	39.1%	**9.9%**	**37.1%**	**13.9%**	**100.0%**

Table 10: Willing to invest in WEM by ownership

	Ownership		
Amount willing to invest for WEM	**Tenant**	**Owner**	**Sum**
Unsure	-	0.5%	**0.5%**
Minor (<500ZAR; ≈ 30€)	1.5%	7.9%	**9.4%**
Medium (500-4500ZAR)	10.9%	55.4%	**66.3%**
Major (>4500ZAR; ≈ 270€)	1.0%	22.8%	**23.8%**
	13.4%	**86.1%**	**100.0%**

DISCUSSION OF RESULTS

Considering that the residents of Nelson Mandela Bay Municipality (NMBM) had one year to grasp the concept of water restrictions, Table 3 indicates that a scandalous 39.1% of participating households are unsure about their monthly water consumption. This is inexcusable as every household receives a monthly municipality statement which displays the monthly water consumption as well as the billed amount. A comparison of water consumption between the independent variables is impossible because of the “unsure” fraction, which

distorts the statistics. This is very disappointing. This ignorance about water consumption is again reflected in Table 8 which shows that
36.4% of the surveyed households name “unsure where to start” as one of the main barriers, whereby almost half of those households (15.6%) are “unsure” about their water consumption. These findings correspond with the findings of Dodge Data & Analytics (2016) which identified “lack of public awareness” as one of the main barriers to increased sustainability in South Africa. When considering to reduce consumption, one should obviously start by “establishing a water consumption baseline” and compile a water use audit of typical household activities. But from the authors own experience that is easier said than done.

According to Hankinson & Breytenbach (2013) and Dodge Data & Analytics (2016) costs are another top barrier to the implementation of sustainable measures. This is supported by an Australian study which expands the barriers to be the perceptions of inconvenience and impracticality apart from cost (Dolnicar and Hurlimann, 2010). The respondents in this study confirm this finding. As per Table 8 “unsure where to start” as well as “cost” are on par with 36.4%. However, the results of this study clearly show that “costs” is only a perceived factor for not implementing water saving measures. The “real” issue is the ignorance of water consumption, which is indicated by 13.0% of those households not knowing their water consumption. Water savings can be achieved by changing an attitude towards the scarce resource of fresh water at the price of a bucket, but it is inconvenient.
In contradiction to the results reported above, Table 9 shows that 23.8% of respondents are willing to invest more than 4500ZAR (≈ 270€), which equates to a two-week income of an average South African household. On the other end of the range, 9.4% are only willing to invest a minor amount of not more than 500ZAR (≈ 30€). Surprisingly, the majority of those households (7.9%) are owning the property and would directly benefit from any cost savings in running cost, but when investigated further, most of those households had already installed a water-efficient measure (WEM) or made use of an alternative water source.

Many South Africans and in particular the residents in the Nelson Mandela Bay Municipality are used to water restrictions as it is a re-occurring phenomenon (National-Treasury, 2011), which explains that more than half (56.4%) of the surveyed households do not purely rely on municipal water and 17.8% make use of two (2) or more alternative water sources (Table 4). Rainwater harvesting is the main sustainable water source alternative with 34.2% (Table 5). This was expected that rainwater harvesting is the first choice of alternative water sources as the conditions for rainwater harvesting are more conducive in South Africa than in the highly populated European countries. In South Africa, most residential buildings are single-storey with large erfs. Furthermore, rainwater harvesting is historically very common in the urban areas of South Africa.
According to Marais (2016), some guesthouses around NMBM have retrofitted their respective properties by installing greywater systems and rainwater storage tanks. These are promising signs for the implementation of water-efficient measures around NMBM. However, Marais (2016) points out, that these installations are predominantly spurred by the economic aspects instead of long-term sustainability. The residents of Nelson Mandela Metropolitan Municipality

(NMBM) move in the right direction. Table 5 shows that as much as 14.2% recycle their greywater (Table 5), from which 7.9% indicated "manual greywater recycling". People re-use bath- and shower water for flushing toilets, watering the garden or washing clothes, defying the inconvenience of carrying buckets of water from one location to another. Greywater recycling is the "first choice" when more than one alternative water resource is used. Borehole installation and rainwater harvesting require a substantial capital investment which results in the fact, that households select either rainwater harvesting or borehole installation.

A scandalous 38.1% of the participating households have no water-efficient measure (WEM) installed (Table 6), considered that water saving shower heads are available for less than 200ZAR (≈ 15€) and that the participating households are not from the low-income category. Almost two third (61.9%) of the sample data make use of at least one (1) WEM with 28.7% using two or more water-efficient measures (WEM). Nonetheless, it is surprising that 22.3% of households with at least one (1) WEM are "unsure" of their water consumption compared to 16.8% of households with no WEM. This finding is unexpected but could be explained by people's perception that monitoring water consumption is unnecessary since alternative water sources in addition to the municipal water are used. A similar attitude was observed by Fielding, Russell & Grace (2010) in Australia, who state, that "An important belief was that installation of water-efficient appliances has the advantage of lowering the need to monitor and be vigilant about everyday water using practices when water-efficient appliances were in use."

CONCLUSIONS

The understanding of the current water crisis by the participating Nelson Mandela Bay Municipality (NMBM) households is limited. A large proportion of the participating households is oblivious to their water consumption, which means that ignorant households waste any water conservation efforts made by diligent families. The NMBM is continuously improving its efforts to raise awareness about the on-going water crisis. This is visible in the number of "Waterwise" posters around the city, reminding people to save water, showcasing tips to conserve water and raising awareness about water-wasteful activities or "non-activities" like not fixing a dripping tap. The mayor, Athol Trollip, has resorted in lending radio advertisements his voice and personally propagates water conservation in the three major languages of the NMBM region. Those actions should raise public awareness which Dodge Data & Analytics (2016) named as one of South Africa's main barriers to increase sustainability.

The Premier of the Western Cape, Helen Zille, stated in a TV interview that people's attitudes and views towards water needed to change, similar to the change in attitude towards energy after South Africa's energy crisis some years prior (Watts and Webb, 2017). Cape Town's residents have proven that it is possible to cut down water consumption substantially, but the increase in water conservation has uncovered another challenge, the city of Cape Town's income also dropped considerably. Cape Town had to re-structure its tariffs to cover the cost for reticulation and supply of water (Etheridge, 2018).

In May 2017 the Nelson Mandela Bay Municipality was declared a water emergency area which resulted in higher water charges on the one hand and made provision for the installation of water flow restrictors for "wasteful" domestic users on the other hand. While the city of Cape

Town made headlines for “naming and shaming” as well as conducted “raids” against high water consumers and installing water restrictors, the authors wonder if the NMBM ever implemented water restrictors. It certainly never made the news.

The residents of the NMBM identified “cost” as a barrier to implement water-efficient measures in their households which corresponds with the findings of Dodge Data & Analytics (2016). The same publication also identified “lack of political support and incentives” to be a challenge for increased sustainability in South Africa. Year after year, research identifies the same barriers, but the implementation of policies takes time. The South African policymakers can draw from a large pool of ideas to drive sustainability. The city of Cape Town has shown that great newspaper coverage and holding people accountable, reduced water consumption. However, research has not yet been published to identify the exact triggers which successfully changed Cape Town’s residents’ behaviour.

Water is a precious natural resource and must be conserved. Water conservation has two sides to it, the consumer must consume less, and the government must establish alternative water sources as well as reduce any losses when collecting, storing and reticulate freshwater. WHO & UNICEF (2017) predict that climate change will lead to greater fluctuations in rainwater which will significantly affect South Africa’s water supply. South Africa’s Department of Water and Sanitation (DWS) has acknowledged in its “National Water Resource Strategy” that South Africa requires a multitude of strategies, including water conservation and water demand management, and amongst others a further utilisation of groundwater, desalination, water reuse, rainwater harvesting and treated acid mine drainage (Department of Water and Sanitation South Africa (DWS), 2013). Furthermore, the dilapidated infrastructure and leaks have to be addressed (du Plessis, 2017).
According to reports by local newspapers, the Nelson Mandela Bay Municipality (NMBM) has been in a constant battle with its water resources since the drought of 2010 (NationalTreasury, 2011). The fact that NMBM water has been a cause for concern over the past seven years should lend itself to propagate and promote water conservation behaviour. However, only 9.9% of participating households consumed water sparingly and within the requested amount of 70l per day per person at the time of the survey.

As mentioned before, this study is the first of its kind conducted at a unique point in time twelve (12) months after water restrictions were imposed on the NMBM residents. Future studies are recommended to validate the results of this study and to establish longitudinal results as water consumption is amongst others influenced by locality, climate and water restrictions (Dolnicar & Hurlimann, 2010).

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Smart Cities

SMART CONNECTED HOMES: INTEGRATING SENSOR, OCCUPANT AND BIM DATA FOR BUILDING PERFORMANCE ANALYSIS

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Abstract

Buildings produce huge volumes of data such as BIM, sensor, occupant and building maintenance data. Data is spread across multiple disconnected systems in numerous formats, making it difficult to identify performance gaps between building design and use. Better methods for gathering and analysing data can be used to support building managers with managing building performance. The knowledge can also be fed back to designers and contractors to help close the performance gaps. We have developed a platform to integrate BIM, sensor and occupant data for providing actionable advice for building managers. A social housing organisation is acting as a use case for the platform. A methodology for developing the information needs to support data capture across disconnected systems is proposed and the challenges of bringing data-sets together to provide meaningful information to building owners and managers are presented.

INTRODUCTION

An estimated 10% (2.4 million) households in England are managed by housing associations and funded through government (Ministry of Housing, Communities & Local Government, 2017). Repair and maintenance of housing association assets falls to organisations commissioned and managed by local authorities. Publicly funded organisations such as social housing landlords come under increased pressure to reduce costs of repair and maintenance activities. The three most important areas of failure in buildings are caused through impact from weather, occupants and moisture generated from wet areas within buildings such as kitchens and bathrooms (Chong & Low, 2006). Cause of such failures provide an opportunity to investigate methodologies for understanding building performance in use against design recommendations.

Developing a platform to support repair and maintenance activities of large estate portfolio managers requires a method for understanding the organisation's information needs. This paper presents an approach for identifying: data sources for addressing those needs; and methods for capturing other data such as real-time sensor or occupant data to complete information requirements. The project is an Innovate UK funded collaborative project between Northumbria University, BIM Academy Enterprises and National Energy

Foundation (NEF). A user-centred approach to understanding information requirements for managing and organising building repairs and maintenance is described. A social housing organisation responsible for managing over 26,700 council owned properties presents a case study for this paper.

METHODOLOGY

Understanding the Information Requirements

Interviews were held with the social housing organisation's Asset Information Manager and Technical Surveyor, who deal with enquiries about and facilitate actions on, repair and maintenance issues for housing assets. From these interviews a set of use cases were developed. A follow up workshop with wider participation from the social housing organisation and local authority staff was held to evaluate and refine the use cases and understand data requirements.

Identifying Data Sources

For each use case, existing data sources were identified to better understand factors from building design and occupant activity that impacted building performance in use. Sensor platforms for measuring data such as temperature and humidity were identified and evaluated to support gaps in current data.

Site and Occupants

A newly developed site containing a mixture of 1, 2 and 3 bedroom apartments to be managed and maintained by the social housing organisation was chosen for the study. Tenants attending information events, hosted by the social housing organisation, about the site were informed of the study details. The social housing organisation gained consent for researchers to install sensors within the apartments from tenants applying for properties.

Prototype Development

A prototype sensor visualisation platform was designed to connect in-use performance data to Building Information Modelling (BIM) context data to provide actionable advice for landlords and tenants for minimising repair and maintenance activities. A mock-up graphical user interface was developed with simulated data and backend processing. A web data visualisation platform was required to visualise data to users. The platform was designed to be sensor agnostic and allow integration of multiple data types such as sensor, BIM, occupant survey or energy performance forecast data. Figure 2 demonstrates the platform system architecture.

A second workshop was held with the social housing organisation staff that manage and respond to repair and maintenance enquiries to evaluate the prototype. This workshop took a scenario based design approach to exploring how different users would use the system to perform the activities identified in the use cases developed in the first workshop. Scenario based design is a technique that describes how people will use a system to accomplish activities (Rosson, 2009). Scenarios are stories that describe a sequence of actions and events that lead to an outcome. The design phase in scenario based design involves developing activity scenarios, then information

scenarios then interaction scenarios. The scenarios were designed around two approaches for notifying staff of building defects:

1. Tenant calls social housing organisation support centre to report a problem within a property.
2. Sensor platform notifies social housing organisation staff of a problem within a property.

The follow up process for each approach would be: Staff use prototype platform to identify potential problem cause. Staff either contact tenant and provide advice on how to resolve the problem, or visit the property to investigate further.

Each scenario was tested and evaluated with real-time, in-use data with workshop participants. Each scenario, based on a use case, was presented to participants. Data types for providing information for each use case was demonstrated. Methods for turning data into meaningful advice were explored. Methods such as email, text message or alerts, for notifying the social housing organisation contact centre of problems, were identified and discussed during scenario testing with workshop participants.

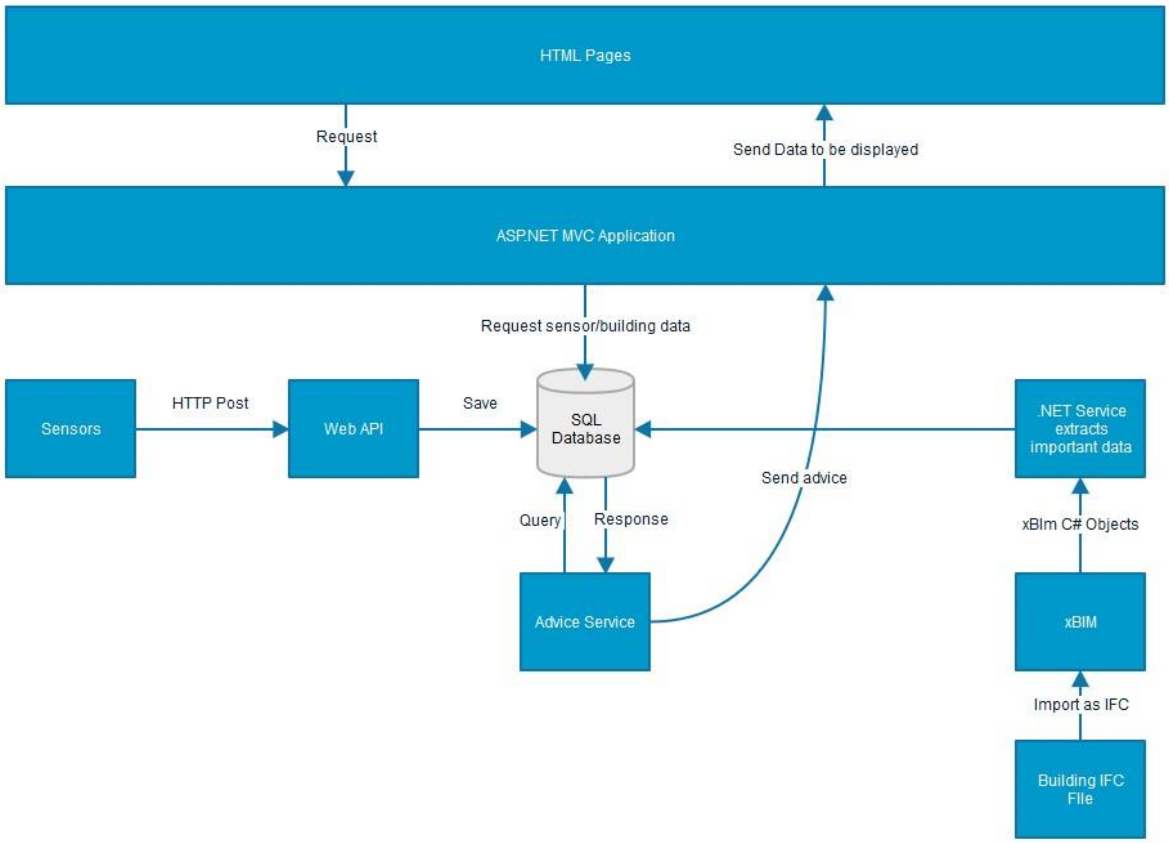

Figure 1 Platform Architecture

FINDINGS

Use Case Requirements

Fifteen use cases were identified within the first workshop: four related to energy cost savings; eight to occupancy comfort and health; and three to building performance. Cost related use cases focussed on creating cost savings for tenants. Data gathered around cost savings could support development of tenant guidance for better managing energy consumption within homes. Comfort and health identified scenarios that affect occupants such as under heating, overheating or damp. System information could support development of tenant guidance on how best to heat and ventilate properties. Building performance related scenarios were designed to identify gaps in building performance design against use. This last category can be fed back to designers and contractors to develop guidelines for creating buildings based on real-time in-use data. Figure 2 shows the data requirements that were identified to support the use cases.

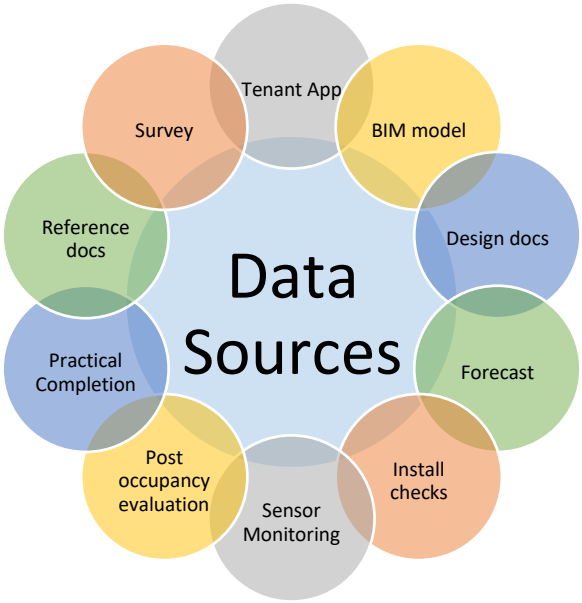

Figure 1 Use Case Data Sources

The following sensors are required to capture the gaps in current data to support the use cases:

- Room temperature (multiple locations per room)
- Humidity
- Door and window open/closed state
- Motion detection
- Ambient Light
- Gas and Electricity Usage

Electricity, boiler temperature, hot water, gas, ambient room temperature, light, humidity and motion sensors were deployed in 7 apartments within a single block.

Prototype Development

A web based prototype was developed linking real-time sensor data to a BIM model (figure 3). The spaces from within the BIM model provide the navigational structure. Selecting a space provides an overview of the space sensor data. Data can be further drilled down into by selecting a sensor to access historical data for that sensor.

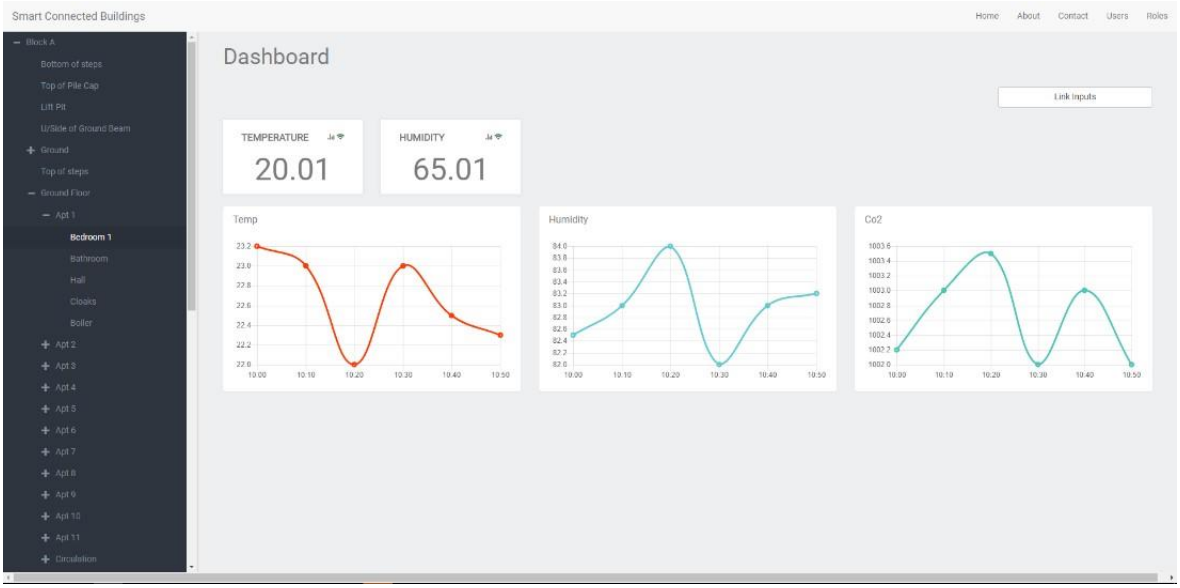

Figure 2 Sensor Visualisation Platform

A number of challenges occurred during system development. For example, the BIM model had front doors that erroneously overlapped spaces and floors, some apartments were incorrectly numbered, floors were unclearly labelled (e.g., 'top of steps'). BIM data had to be cleaned before spaces could be correctly identified and programmatically linked to sensor data. A second problem occurred around sensor deployment, a test deployment was set up and evaluated but when the deployment was installed in multiple homes the environment failed a stress test. This was resolved by installing each sensor network as an individual deployment with its own router on each floor of the apartments.

CONCLUSION

The project has successfully developed an approach for identifying sensor requirements based on a use case scenario based methodology. The project presents a number of opportunities for further developments that would benefit owners and managers of large building portfolios. Being able to measure real-time in-use post-occupancy performance data against design would

provide landlords with clear guidelines to issue to building designers and contractors for new work. User satisfaction of the building can be measured against building design and performance using the platform. Having the ability to compare user satisfaction against performance allows landlords to identify problem areas and better inform tenants how to use their buildings.

Further developments to the prototype include a 3D viewer for visualising the data inputs per apartment. Having a 3D view will allow users to visualise where an apartment is within a block and assess environmental characteristics such as orientation and solar gain. Linking building fabric and infrastructure data to environmental data would enable further analysis of different data sources to assess components such as the thermal comfort and thermal dynamics of a building. Currently the system has been evaluated with a single social housing provider but further workshops are planned to evaluate the system with social housing landlords from other regions within the UK.

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REACHING THE PERFORMANCE "SWEET SPOT" WITH CERTAINTY

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Keywords: building performance, design quality, management, POE

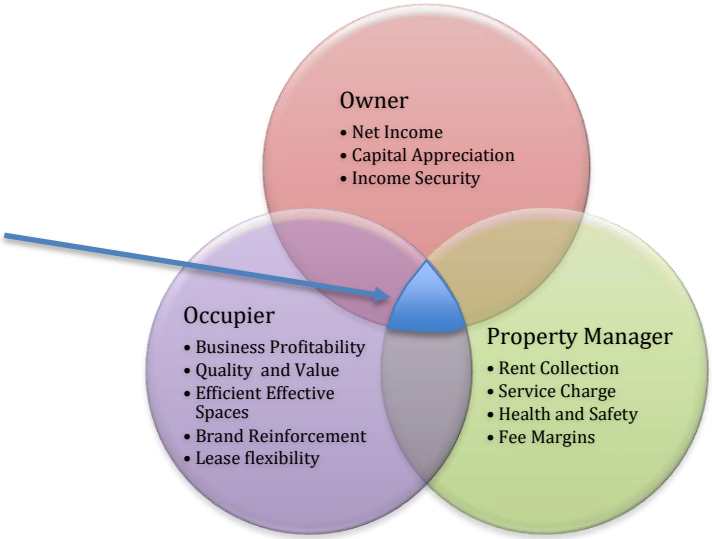
ABSTRACT

The search for the so-called "performance sweet spot" (1) within buildings has tended to concentrate on the investigation of narrow technical issues, usually citing poor design, construction detailing or even controls complexity as the primary causes. New research (2) suggests the reasons for errant building performance is significantly more complex than designers understanding, involving metaphysical, sociological, even psychological and cultural factors which lie largely ignored. In addition, resistant and highly conservative protocols within the construction industry conspire to create added misalignment (3), further compromising building user's expectations for a successful building product outcome. The quest for better appreciation by designers and constructors of these complex issues is an urgent one if the industry is to meet the needs of its customers for ever more demanding, healthy and sustainable buildings. This paper examines the divergent issues for designers and users, and how using more customer-focused approaches, design and engagement processes might be better initiated and informed. All with a view to improved user aspirations for buildings which provide a home for better user outcomes, higher quality and lower costs. One where building users and designer's efforts are truly aligned to hit the "performance sweet spot" with repeatable certainty.

INTRODUCTION

A recent report (1) by the British Council for Offices (BCO), following a survey of over 2,000 of property industry clients concluded: "*the property industry is lagging well behind other industries in the customer service revolution*". The report went on to say, *"occupiers would like … a far more sophisticated approach…to see attention switch from a one-dimensional focus on [contractual] capital value and/or income appreciation to finding the 'performance sweet spot' – the point at which the owner, manager and occupier are aligned ...and where potentially greater value can be released*".

Owners/Managers/Occupiers would like to see the property industry provide buildings which hit the sweet spot with more certainty:



Courtesy of British Council for Offices

Figure 1. The "performance sweet spot" between Owner, Occupier and Property Manager Interests

The search for *"the performance sweet spot"* amongst design and construction professionals, has until now tended to involve the post-occupancy investigation of narrower, more technical issues, usually concentrating on poor construction information or design and controls complexity as the root causes, none of which are likely to accentuate the interest of owners or users.

Similarly, recent research into the methods used by post occupancy researchers has tended to overlook the fact that users require a different value proposition (2) from that on offer within the industry's studies. It is apparent that at the interfaces between buildings and users, there are sociological, even psychological and cultural, as well as technical issues at play, none of which are being addressed in the feedback to the industry. In addition, hardwired procedural protocols within building design teams conspire to create even further misalignment with user's expectations (3), all of which compromises the design team's ability to achieve a wholly successful outcome.

The search for a deeper understanding to these complicated issues has led the author to undertake an investigation into why the property industry has fallen short in overlooking the real needs of its customers. This paper explores how other industries have successfully addressed similar problems in living up to the expectations of users, and how by using similar design management techniques to them, the property industry might replicate this success in meeting users' needs to hit the defined "performance sweet spot" with certainty.

CONTEXT

In 2011 Monfared (4) study of the perception of users of a modern award-winning BREEAM Excellent building provided disturbing evidence that users have entirely different expectations to those of designers. Following a carefully constructed and monitored the 3year longitudinal

investigation of building occupant's perceptions, the study concluded, the "satisfaction of occupants with a building" is most closely derived from three distinctly social elements: -

- Increased productivity
- Feelings of improved health and wellbeing (in comparison to other buildings)
- Feelings of contentment with features and facilities.

Monfared went on to cite Newsham (2009) (5) who suggested that the two most common features studied and measured by researchers in forming conclusions on the measurement of "satisfaction of occupants with a building" where technical:-

- Perception of environmental comfort
- Control over environmental conditions

In the search for why buildings are failing occupants, it seems it is the norm for designers and architects to devise post-occupancy evaluation (POE) studies which measure success from their own technically familiar perspective, rather than from that of the users whose view of their building is established using very different criteria.

Deuble et al. (2014) (2) evaluated the responses of occupants to a POE across two similar office buildings on the same university campus. The study established that occupant complaints of discomfort within one of the two buildings could not be explained by actual measured comfort data in the spaces. There was a reason to believe that occupants of the "defective" office had a unique perspective which was informed by business needs, organisational culture and general job satisfaction, thus motivating the negative returns made on the POE questionnaires. The study concluded that where POE's concentrate on technical issues alone, they cannot adequately evaluate the overall performance of a building, nor the extent to which the project meets the needs of its end users (Vischer (2009) (6)). A more holistic and robust performance evaluation is required if researchers are to understand how occupants view their building. One that incorporates an assessment of physical environmental data collection in parallel with occupant subjective metaphysical occupant responses, as suggested by (Ventre (1988) (7) Preiser (2001) (8); Vischer (2001) (6); Loftness et al.(2009 ((9)).

It seems that looking at issues from a building users perspective, is not something that should just be confined to the POE process. Moezzi (2009) (10) concludes: the "*fascination [by designers] with* the *performance of engineering systems and the quality of their installation and control*" has tended to introduce high expectations of them [the building's systems]. Hopes that they can seldom live up to.

Heerwagen et al. (2005) (11) reinforces this point following review of a number of green buildings to advocate;

- Buildings are relevant to business [users] interests across the full spectrum of concerns, from portfolio issues (e.g., the resale value of the property) to enhanced quality of individual workspaces (through improved ambient conditions).

- Because the potential influence of [green] buildings is broad, research on green buildings should address a range of outcomes rather than focusing narrowly on just a few. Issues of interest to organisations include workforce attraction and retention, quality of work life, work output, and customer relationships.

- Buildings can provide both cost reduction benefits and value-added benefits. The emphasis to date, however, has been on costs, rather than on benefits. The need for more data on value-added benefits underscores the importance of studies that focus on these human and organisational factors.

All of which leads to the question, can buildings be systematically designed in ways which can illicit with more certainty, by incorporating user's agency and sense of belonging to it, i.e. "the sweet spot *where potentially greater value can be released"?*

User Centric Design: Origins

In consideration of this, investigations to source a more flexible set of user-centric design management tools commenced with a review of project management methodologies deployed in other user-centric, customer orientated sectors of the global economy.

The study found that the hospitality, technology media and telecommunications (TMT), aeronautics, and automotive industries each invest large sums annually in researching customer experience. Within the TMT industry, a specialist sub-sector "UX" an acronym for user experience matured, which formed around what are known as Agile Project Management (APM) techniques, and which have come to dominate the project management disiplines of modern day software and application development. So much so, APM has overtaken PRojects IN Controlled Environments (PRINCE2) as the preferred design tool methodology in these sectors over the last three decades.

APM grew out of the post-war United States, European and Japanese war rebuilding programmes where automation and efficiency were needed to offset the loss of workingage labour. Over the next fifty years, Agile Methods (unfortunate naming terminology sometimes confused with Lean and Kanban or agile office design, which are somewhat different) was recognised as the solution to solve the inherent inadequacies of conventional Taylorism PRINCE2 software design management approaches.

Continuing the development of APM into the 1970's Winston Royston (1971) (12) coined the term "waterfall", as an almost derogatory descriptor for Taylorism in project management,

i.e. following a linear process and falling over weirs or milestones to the next stage. Inferring that once the process flow had commenced, it became difficult to halt the momentum generated, and the project went with the flow to completion, as is the case in construction today.

Royston contended that with waterfall, the certainty of satisfaction with the outcome is not determined until the process is complete. Cost and time estimation is an estimation and is invariably wrong.

Reis (13). is more scathing of Taylorism's waterfall process noting several defects;

- **Scope Bloat**. - Cram in as much as the budget can afford. Aspirations usually exceed budget eventually leading to cost overrun and "de-value engineering".
- **Blind Investment** – cost risk remains and is only mitigated on completion.
- **Architectural Risk** - Design risks come to surface too late
- **Functional Risk** – Users don't get to know if it works until the end.
- **Change Risk** – Cost risk supersedes change risk, meaning it is never adequately addressed.
- **Uncertain Cost and Duration** – Large numbers of change requests are commonplace.
- **Resource levelling/availability** –Windows of availability never align. Availability of the right people input at the right time is difficult to align, which reduces quality.
- **Team motivatio**n – When projects go wrong commercially, interest wains, quality declines further, user outcomes drop to the bottom of the priority list.

All the above being factors that affect the production of buildings, and which ultimately lead to uncertainty and user dissatisfaction with the outturn product.

Expanding the work of Royston, Deming (14) with the experience of several years troubleshooting projects in post second world war Japan, proposed his 14 principles for project or process management success.

From his experiences, Deming observed that the failure of a project was usually the product of a management process failure, rather than a failure of execution or the competence of the operatives implementing it. He noted that managers of the failed projects also tended to diagnose the causes of their inability by incorrectly attributing the reasons for project failures on technical non-compliance or operative incompetence. In most cases, Deming observed, the failure had its origins in the generation, management and care taken over the quality of information arriving or leaving the design table, and usually had little to do with the execution of the planned procedure at site level.

Deming proposed that projects should have the core purpose of increasing quality for the customer from the outset. Where quality becomes the focus, the project team would find better ways to reduce time and cost by default.

The 14 principles led Deming to the corollary;

a) When people and organisations focus primarily on quality (of information), defined by the following ratio,

$$\text{Quality} = \frac{\text{Results of work efforts}}{\text{Total costs}}$$

quality (of the product) tends to increase, and costs fall over time.

(b) However, when people and organisations focus primarily on *costs*, costs tend to rise and quality declines over time.

This movement towards improving quality and a focus on how information flows within the design process became Deming's theory for advocating a separate design management process, splitting and separating the management of the design from the management of the construction process.

Swayed by the need to improve the quality of information on the design table, at IBM Weinberg (1971) (15), Jacobson et al.(1991) (16), and Kilb (1998) (17) brought forward thinking on "adaptive" software development, following on in the 1990s, to eventually be called *lightweight* software development methods. Lightweight development includes Agile Methods, all evolving in reaction to the perceived inadequacies of heavyweight Taylorism methods.

The common thread for the all Agile Methods (including Scrum which became the predominant of all of the above Agile methodologies) is in integrating feedback from users at the very earliest stages in the design process. This is achieved by incorporation of rapid prototyping, testing and even trial and error early in the design process, as a means of eradicating the risk of failure associated with rejection of the product by users post launch to the market. Due to their deeper involvement, users become the custodians of product quality while also sustaining customer change requirements and innovation feedback loops for a de-risked product outcome.

Through the mid-1990's, IBM with other large software and manufacturing corporates continued to improve in-house lightweight Agile Methods to produce Dynamic Systems Development Method (DSDM), Scrum, Crystal Clear, and Extreme Programming (XP). All these lightweight methods became variant subsets of the Agile Project Management philosophy. In parallel, research into lightweight APM techniques (or more commonly referred to as Agile Methods) continued in the automotive, manufacturing (1991) (22) and aerospace sectors.

Proliferation of Agile Methodologies in Industry (mainly TMT)

In 2001, seventeen software developers all prominent proponents of lightweight project development, met in Utah to discuss how they might promote the apparent benefits of lightweight methods to a broader audience. To this point, the take-up of the methodologies was mainly confined to the major corporates. In response, Fowler and Highsmith published The Agile Manifesto (2001) (18).

At the heart the manifesto are 12 principles (recommended to be read in full) which distil into four key themes as follows;

- **Individuals and Interactions over processes and tools** - Prioritising the quality of people and face to face collaboration above siloed activity with a prescribed project managed process
- ***Working product over comprehensive documentation. -*** Concentrate on how the product should work, and back cast this to the design process, over (not instead of) concentrating on producing a competent set of design specifications on time and on programme.
- ***Customer Collaboration*** *over contract negotiation – Manage the quality rather than the cost.*
- ***Responding to Change*** *over following a plan – Invite change to improve quality, the product is more important than the plan.*

The group went on to form the Agile Alliance, to further the development of Agile Methods across TMT and to promote adoption and training in its implementation.

In 2011 the Agile Alliance created the Guide to Agile Practices (renamed the Agile Glossary in (2016), an evolving open-source compendium of the working definitions of agile practices, terms, and elements, along with interpretations and experience guidelines from the now global community of agile practitioners.

Agile Use in Construction.

In recognition of findings of building POE research above, and the absence of focus on customer outcomes it seemed valid to ask if Agile Methods with its clear focus on customer outcomes could be of benefit to the construction industry? If so, how should Agile be deployed? Are the synergies of the TMT industry with that of construction strong enough to effect a successful introduction of Agile Methods, and if so how might it be achieved?

To begin with, a search was conducted to find instances where Agile Methods were deployed within the construction sector. The search located a small number of academic research papers with case study projects in Europe and the United States.

Owen and Koskela [2006] (19) undertook an analysis of the applicability of Agile to construction. The study references the work of Stapleton (20) and the DSDM Consortium following an EC funded pan-European research to identify the benefits of the broader use of Agile Methods for process improvements. The study found that where projects had adopted DSDM, significant

enhancements resulted, which included a 23% improvement in the number of survey respondents who agreed or strongly agreed that delivery and client satisfaction had improved as illustrated below;

Objective	Target Improvement	Actual Improvement
Improve on-time delivery and customer satisfaction	20%	23%
Increase process predictability, higher maturity level	10%	40%
Improve organisational skills of both management and development of personnel	20%	79%

Table 1 DSDM in Process Improvement (Source Stapleton and DSDM Consortium (2003) (21))

The Owen and Koskela paper highlights the Shine Industries (2003) (21) online survey of companies who had used agile methods in their projects. The clear majority of respondents reported high or significant improvements in productivity, quality, and business satisfaction (see table 2 below).

Did Agile process result in:	Yes	Neutral	No
Reduction or significant reduction in cost	49%	46%	5%
Better or significantly better productivity	93%	5%	2%
Better or significantly better quality	88%	16%	1%
Better or significantly better business (user) satisfaction	83%	16%	1%

Table 2 Agile survey results (source Shine (2003)

Everts et al. (2011) (22) study documents the use of Scrum on a private rented new build residential project in Switzerland. Concluding that while new construction assignments require new (lightweight) more “human centred” management paradigms, existing paradigms [Taylorism] are tenacious in their hold on existing industry project and design management thinking.

Streule et al. (2016) (23) recorded a case study in the use of Agile Methods on a private residential scheme designed and built in Switzerland by property developer Swiss Property A.G. Agile Methods were applied across the design phases leaving the site level construction phases to revert to traditional PRINCE2 methods.

The methodology was deemed by participants to work well, albeit with some acknowledged issues of inexperience in the deployment of the method. It appears existing familiarities with waterfall methods were slow to be relinquished. But the paper concludes that this should not impede wider implementation of Agile Methods across the industry, suggesting it should even be extended into the construction phases, particularly on complex rapidly changing projects.

In all cases cited above, it appears Agile was deployed to improve information quality within the project management process as a basis for developing efficiency and productivity of the project implementation phases. There is little evidence to suggest any specific intention to improve outcomes for users of the final built product, with no evidence of the involvement of future users of the developed product during the design processes.

However small in numbers, the cited studies established a precedent for successful deployment of the methodology and meaningful grounds for proposing new approaches that could lead to broader adoption across the construction industry.

Agile for Buildings – A new methodology

While it is apparent that Agile Methods or an adapted variant of Agile has merit in providing the necessary improved performance outcomes, the property and construction industry continues to be resistant to change (24), to the point where recent events have highlighted obvious market failures.

Given the low appetite of change, it is reasonable to expect the introduction of Agile as a new means to manage the design process (as with the chequered history of Lean and BIM) would need to address perceived difficulties of gaining traction in what is seen as a conservative construction industry. This suggests that the methodology would find a better reception if it could be seeded by the client as a mandatory process to be adopted from the point of decision to procure a new building.

With the recent introduction of the Royal Institute of British Architects (RIBA) Plan of Work 2013 (25) Stage 0: Strategic Definition there is already encouragement that more emphasis should be placed by clients on commencing the process towards achieving quality through deeper and more meaningful engagement with end users.

Also, early in the design process (RIBA Stages 0 to 2) is where the best opportunity for change with the lowest impact on cost and programme exists. And where most value can be extracted from the involvement of the client user teams; particularly when invited to work jointly with designers in co-authoring the new building's design.

The challenge for any new methodology therefore, is to prioritise user outcomes and from here, to work with them towards their version of "the operational sweet spot" with greater purpose and certainty of outcome. This has became the active heart of a proposed new Agile for

Buildings (A4B) proposed by the author. A4B is an Agile methodology adapted for use the property and construction industry. A4B is closely based on the Scrum variant of APM adhering to its generic processes as shown in Fig 1 below. Chosen because of its success in other industries, and proven albeit limited track record in property and construction, the main difference between A4B and conventional Agile Methods Scrum is that it is constricted to apply Agile principles across RIBA Stages 0 to 2 only, where Scrum in TMT might run across the entire project.

The initial goal of the A4B methodology as with Scrum is to extract the knowledge base of all building user stakeholders. Inviting them to be involved as co-authors of the future design, in what becomes a compelling journey towards a new business integrated building and forming the new workplace with real purpose through three active elements. The components of the methodology are as follows;

1 - User Stories: invites users at all levels of the client business to input there own ideas for their new building, recording each idea on record cards or post-it notes. The cards document the issues the users feel should be prioritised within the new design if the building is to demonstrate success for them.

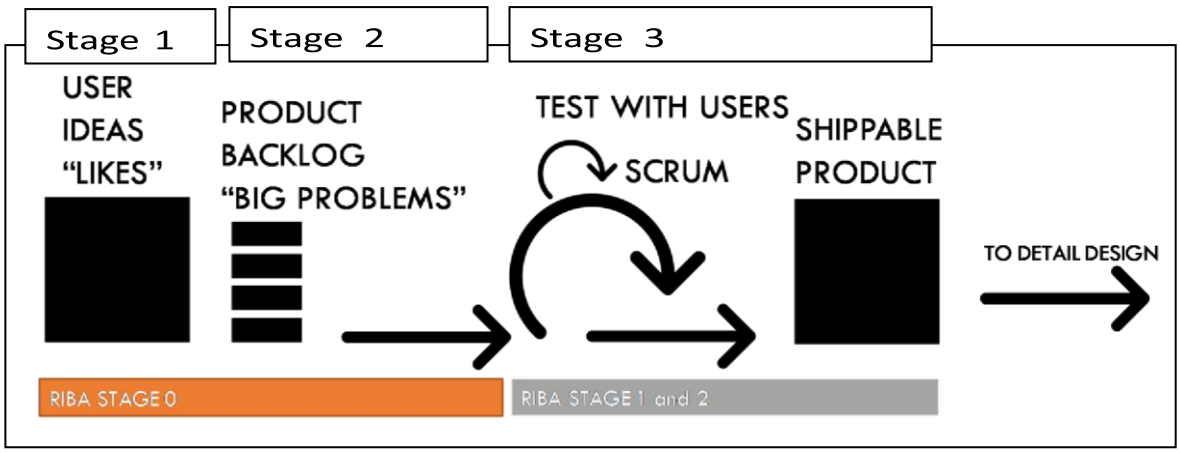


Figure 1. Diagrammatic of an Agile Scrum Process for use in the design of a building

2- Product or Problem Backlog: sifts what could be a multitude of Stage 1: User Story Record Cards from all users and stakeholders, placing them into thematic groupings or "bins" to arrive at a smaller number of larger consolidated thematic problems for resolution. This definitive list of thematic "big problem" categories is called a Product or Problem Backlog (PB). The constituent PB themes are prioritised in favour of highest value and lowest cost at the top, and lowest value and highest cost at the bottom.

3- - Scrum. The Scrum Teams comprising six people or less with up to three representatives of business users and three building design team members to work through each of the PB items. For each thematic PB item, scrum team members are

tasked with the creation of a minimum viable prototype (MVP) to solve the aggregated PB problem. PB items will will be unique to the users and the business or organisation. The developed PB prototype solution must receive users agreement as a solution to the given Backlog Problem.

The MVP ask can take on any form. It can be "*a working prototype model of a new desk layout to promote great team cohesion*", or *a vitual reality model of a new teapoint to promote health and wellbeing*, even a short specification *to deliver the IT solution for a step change in seamless homeworking* . The only prerequisite for the PB and resultant MVP is that it should be capable of being meaningfully tested by expected users before being incorporated as a final product or component of the whole building design.

As well as the designers and business representatives, orthodox Scrum Teams include two other influential individuals. First, the Problem Owner who represents the main body of business users, and says when the business is happy that the problem is solved. Next, the Scrum Master who guides the process, unblocking obstacles to success. When the Problem Owner in consultation with all business users is content with the solution; the working prototype is paired with a short specification description to be handed on to the design team in RIBA Stage 3: Developed Design. At this point the component is integrated into the formal design of the new building as a recognisable customer led feature.

The business Problem Owner will continue to be a guardian of the integration of the prototype solution through design and construction to delivery and final handover of the PB element. The Scrum team maintains responsibility for time and cost, and it is acceptable for the Problem Owner to say when enough time has been spent in search of a solution, even without having achieved success. This Scrum process is repeated for all items in the Product Backlog.

Within the methodology, users frame solutions, participate in their development, and gain the reward of seeing their solutions take shape. They also pick up knowledge through the process, become participants rather than observers, and eventually more informed critics of the construction process. The process will also have spin-offs in using the project to harmonise the user community around common goals, thus improving their engagement with the occupant business and leading to a building which informs a better company. Ultimately creating the conditions, where because they were involved as co-authors of the design, users have an agency with the design and construction process. The design is not done to users but with users. In this way, the necessary sociological aspects of design are addressed, and any subsequent POE is more likely to find improved understanding, greater forgiveness, and a broader sense of community. The defined "performance sweet spot" is achieved with measured certainty.

CONCLUSIONS AND RECOMMENDATIONS

Analysis of the work undertaken within other user-centric industries suggests there is much for the building design and procurement industries to learn.

Published POE studies and those from client bodies such as the British Council for Offices, confirm that there is an issue for the construction industry to address in closing the gap between what is expected by its customers and what is delivered. To add to this, the demands for ever more complex products in energy and the carbon-constrained world continues, in a situation where the industry is struggling to keep pace.

On top of this technological advances, coupled with a health and wellbeing agenda are placing even higher expectations on the performance of buildings by the people who inhabit them.

If the indications are that the construction industry is failing to meet current expectations now, the situation can only exacerbate with time. The industry must find ways to understand the needs of its end user customers and to integrate them more meaningfully into its design processes from the beginning.

The current fixation of the industry with commercial and technical outcomes as benchmarks of success, including its industry perspectives on POE feedback, only serves to compound these constraints, and is to the detriment of customer outcomes.

Lessons learned from other sectors such as TMT indicate that the construction's current preoccupation with cost and contracts, over quality and effectiveness, is ultimately unsustainable, serving only to initiate a "*spiral to the bottom*" as argued by the industry's own seminal report "Modernise or Die". Despite this, the finish and quality of the built environment product is high, while users still find fault and complain. The industry is invariably building the wrong product by placing value in the wrong areas. Users feel the design is being done "to them" not "with them or for them" which is what ultimately lies at the heart of the "performance sweet spot" issue. It seems the logical solution to this situation is to involve users as customers and to do so in significantly more immersive ways.

The TMT industry has much in common with the construction industry where projects are complicated, subject to change and provided to an end-user for use. Agile Methodology which evolved in the TMT industry is proven to work in similar product development industries to that of construction. Successful case studies in construction environments suggest it could also be useful in improving the management of built environment design, by improvement of information from and feedback to users, all leading to improved operational outcomes and the achievement of the defined performance sweet spot.

With this as a new tenant of understanding, Agile for Buildings (A4B) methodology has been developed for use in a live project environment. The next immediate steps must be to fund a longitudinal study of A4B in a number of longitudinal case study projects with clients who are about to procure a new workplace building. There is room for optimism that where Agile Methods is introduced, design teams and clients will conspire from the outset to hit the performance sweet-spot with certainty.

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THE CONCEPT OF SUSTAINABILITY IN SMART CITY DEFINITIONS

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Abstract

Smart cities have emerged as a possible solution to sustainability problems stemming from rapid urbanization. They are considered imperative for a sustainable future. Despite their recent popularity, the literature reveals the lack of conceptual clarity around the term of smart city, due to the plethora of existing definitions. This comprehensive literature review has identified 31 smart city definitions recovered by non-technology focused literature. The definitions are assessed according to the dimensions of sustainability that they consider, environmental, economic or social, and the priority in which they accord the concept of sustainability. The study reveals that not all approaches to smart city incorporate the notion of sustainability in the same way. Additionally, themes emerge according to the dimensions these definitions consider as well as according to whether they derive from the industry or not. Some definitions offer a more balanced holistic view while others appear to be more focused on different smart city goals or variant ways to achieve them. The findings of this study contribute to knowledge and practice by aiding conceptual clarity and, in particular, by drawing attention to underlying assumptions about the role of sustainability in smart city development.

INTRODUCTION

It is estimated that by 2050, 66% of the globe will be residing in cities, compared to approximately 54% residing now (UNEP, 2018). This means that 2.4 billion people will potentially be added to the global urban population. Consequently, this will inevitably result in a significant expansion of existing urban environments and potentially lead to the need to create new ones. Cities use less than 2% of the earth's surface yet consume more than 7 % of the natural resources available globally. The United Nations Environment Programme (UNEP, 2018) estimates that the material consumption related to cities will augment to approximately 90 billion tonnes by 2050 compared to 40 billion tonnes in 2010. Some of these resources are primary energy, raw materials, fossil fuel, water and food (UNEP, 2012). As a result, cities are expected to experience challenges related to growth, performance, competitiveness and residents' livelihood (McKinsey & Company, 2013). Deterioration of liveability functionalities related to challenging waste management, scarce resources, air pollution and traffic congestion that cause human health concerns, as well as ageing public infrastructure, are some of the problems generated by rapid urbanization (Washburn *et al.,* 2009). In order to address these issues, the smart city concept has emerged as one of the possible solutions.

A smart city is a city that may aims to make itself 'smarter', more sustainable, efficient, equitable and liveable (NRDC, 2012). There are numerous definitions of smart city in the

literature many of which are diverse in nature. Their diversity ranges from what elements a city needs to encompass to be deemed as smart, what resources it needs to employ, what characteristics it needs to present, to what are the smart city's goals, purpose and scope. Nevertheless this plethora of definitions creates additional confusion not only to the concept of smart city, but to the role of sustainability as well. This paper is a comprehensive literature review of the role of sustainability in smart city definitions. The goal of the study is to aid conceptual clarity by drawing attention to underlying assumptions about the pivotal role of sustainability in smart city development.

Sustainability as one of the strategic goals of smart cities

The steep growth in urban population and the subsequent increase in resource consumption will inevitably create numerous challenges for cities. This highlights the importance of shifting paradigms in the way cities work in terms of sustainability. To begin, it is important to establish a working definition of sustainability for the purposes of this study. Allen and Hoekstra (1993) highlight the importance of establishing the scale on which a system is being assessed in terms of sustainability. Achieving sustainability on a global scale requires different type of actions than on an urban scale. There is no single best-established definition in terms of sustainability in the urban scale nevertheless there is a commonly-used set of characteristics of urban sustainability. These include intergenerational equity, intra- generational equity (social, geographical and governance equity), conservation of the natural environment, significant reduction of the use of nonrenewable resources, economic vitality and diversity, autonomy in communities, citizen wellbeing, and gratification of fundamental human needs (Maclaren, 1996).

These characteristics incorporate the three dimensions of sustainability: the environmental, the economic and the social dimension (Lehtonen, 2004), where the environmental regards the ecological aspect and includes the conservation of the natural environment (flora and fauna) and resources and an energy production based economy, the social dimension includes equity, community autonomy, citizen well-being, and gratification of fundamental human needs, and the economic consists of the economic vitality and diversity of the urban area. For the context of this research an urban environment can be sustainable when social equity, conservation of the natural environment and its resources, economic vitality and quality of life are achieved. Urban sustainability appears to be one of the prevailing themes in smart city literature, but to what extent is the concept embedded in the understanding of smart cities and how comprehensively is it addressed?

METHODOLOGY

This research aims to provide a comprehensive review of the role of sustainability in smart city definitions in the literature. The definitions presented have been retrieved from academic papers on the conceptualization of smart cities, from organizational and government reports, as well as from documents and reports produced by industrial actors. The academic definitions were searched through inserting relevant keywords in the Elsevier's Scopus database. Solely English language papers were selected. As the research field of smart city is multidisciplinary and diffused, the following subject areas were selected: social sciences, environmental science,

energy and business management and accounting. Computer science, engineering and mathematics related papers were not consulted, in order to keep the focus on the conceptual part of the subject in question and not focus on the technological side of smart city. The keywords were ("smart city", "smart cities" AND "definition") occurring in the abstract. The most highly cited papers were selected and examined. From these, original definitions that explored the conceptualization of smart city were selected and included in the review.

Secondly, a list of smart city organizations was retrieved through the partnership list of the United Smart Cities organization, coordinated by the Organization for International Relations (OiER) and the United Nations Economic Commission for Europe (UNECE). Documents produced by these organizations were assessed and original definitions were retrieved. Finally, the list of industrial players was composed through a combination of the United Smart Cities organization industry partners database and the Future Cities Catapult industry database, the latter being the leading smart cities organization in the UK created by the Department for Business, Innovation and Skills (BIS). Reports produced by industrial partners were reviewed and original definitions were retrieved. Definitions that appeared repetitive were discarded in order to generate a streamlined/focused dataset. From the 117 articles found in Scopus, 17 original non-repetitive definitions were retrieved. From the 12 organizations found, six definitions were identified and from the 24 industry players, eight definitions have been included in this review.
The analytic method evaluated the definitions retrieved according to:

a. Whether sustainability, defined in this context as the coexistence of social equity, conservation of the natural environment, economic vitality and quality of life in the urban environment, is considered as one of the smart city goals;
b. Which dimensions of sustainability, environmental, social or economic, are taken into account;
c. How sustainability goals are prioritized. Prioritization was assessed according to whether sustainability appeared as a primary, secondary or tertiary goal, where primary was indicated as of fundamental importance, secondary as important but not fundamental goal and tertiary a goal of less importance compared to the other two categories. Although subjectively classified, the three level of priority offer an indication on the centrality of sustainability in smart cities definitions.

FINDINGS

This study identified 31 definitions in the literature, the majority of which come from academia (17 definitions), while six were found in organizational/government reports and eight in documents from the industry. An overview of the definitions is first presented, followed by more detailed examination of the variances in sustainability oriented and non sustainability oriented definitions. Subsequently, the dimensions of sustainability, namely the environmental, economic and social dimension, as well as the prioritization of sustainability as a smart city goal in the definitions, are presented.

Overview of Smart City definitions

Numerous definitions encompass all three dimensions of sustainability namely, environmental, economic and societal, while others examine only one or a combination of two. Subsequently, the definitions have been examined according to their priority as a primary, secondary and tertiary and categorized into a table according to their attributes (Table 1). Smart city definitions are heterogeneous in nature (Ponting, 2013), as there appears to be neither a predetermined template, nor a one-size fits-all definition of what the term smart city encompasses (O'Grady and O'Hare, 2012). As such, definitions tackle different perspectives of smart city development ranging from the adoption of Information and Communication Technology (ICT), user communication, e-governance and equitable development to education and sustainability.

Author	Keywords	Sustainability oriented	Environmental	Economic	Social	Priority
Academic Definitions						
Bakici et al. (2012)	High-tech, connections, ICT, sustainable, greener city, competitive, innovative	•	•	•	•	Primary
Barrionuevo *etal.* (2012)	Technology, resources, integrated, habitable, sustainable	•	x	x	•	Secondary
Batty et al. (2012)	ICT, infrastructures, coordinated, equitable, engaging	x	x	x	x	N/A
Belissent (2010)	ICT, infrastructure, interactivity, efficiency	x	x	x	x	N/A
Caragliu et al. (2011)	Human and social capital, ICT, Infrastructure, sustainable economic growth, quality of life, participatory governance	•	•	•	•	Primary
Chen(2010)	Communications and sensor capabilities, infrastructures, optimization, quality of life	x	x	x	x	N/A
Lazaroiu and Roscia (2012)	Technology, interconnected, sustainable, comfortable, attractive and secure	•	x	x	•	Secondary
Giffinger et al., (2007)	Economy, mobility, environment, people, living, governance	•	•	•	•	Primary
Kourtit and Nijkamp (2012)	Knowledge-intensive creative strategies, socio-economic, ecological, logistic competitive, human capital infrastructural, social and entrepreneurial capital	•	•	•	•	Primary
Kourtit *et al.* (2012)	Productivity, education, knowledge intensive jobs, creative, sustainability oriented	•	x	x	•	Tertiary
Nam and Pardo (2011)	Information, infrastructure, efficiency, mobility, decision making	•	•	x	•	Primary

Schaffers et al. (2012)	ICT, social and environmental capital, competitiveness	•	•	x	•	Secondary
Thuzar (2011)	Sustainable urban development policies, equity, sustainable economic development, human social capital, natural resources	•	•	•	•	Secondary
Toppeta, D. (2010)	ICT, governance, sustainability, liveability	•	x	x	•	Primary
Zygiaris (2013)	Innovative socio-technical and socio-economic growth, green, interconnected, intelligent, knowledgeable, innovating, interactive	•	•	•	•	Secondary
Industrial Definitions						
Alcatel Lucent (2011)	ICTs, competitiveness, environmental sustainability, liveability.	•	•	•	•	Secondary
ARUP (2011)	Engaged citizens, efficient, interactive, engaging, adaptive and flexible city	x	x	x	x	N/A
CISCO (2012)	ICT, increase efficiencies, reduce costs, quality of life	x	x	x	x	N/A
Fiberhome Technologies, (2017)	Data integration, policy, technology, process, capital	x	x	x	x	N/A
HITACHI (2012)	Environment, safe, quality of life	•	•	x	•	Primary
IBM (2018)	Interconnected information, operations, optimization of resources	x	x	x	x	N/A
Schneider-Electric (2014)	Efficient, liveable, sustainable	•	•	x	•	Primary
Telefonica (2016)	Improving public services, quality of life, governance, sustainability	•	x	x	•	Tertiary
Organizational/Governmental Definitions						
BIS (2013)	Liveable, resilient, engaging, hard infrastructure, social capital	•	x	•	•	Tertiary
BSI (2014)	Integrative, physical, digital and human systems, sustainable, inclusive	•	x	x	•	Secondary
Azkuna (2012)	ICT, infrastructure, efficient, citizen awareness	x	x	x	x	N/A
EIP-SCC (2013)	Energy, materials, services and capital, sustainable economic development, resilience, quality of life	•	•	•	•	Primary
EIP-SCC (2013)	Technologies, environmental impact, better lives, governance	•	•	x	•	Primary
ICLEI (2017)	Operations, sustainable, resilient, physical and social capital	•	•	•	•	Primary
IDA (2012)	ICT, real-time analysis, sustainable economic development.	•	x	•	x	Primary
NRDC (2014)	Efficient, sustainable, equitable, liveable	•	•	x	•	Primary

Table 1: Keywords of the definitions retrieved by the literature, where the dot (•) means that this element is present in the definition while the cross (x) means that this element is not included. Table created by the author.

Smart cities can be viewed as cities performing well on six characteristics: environment, economy, mobility, people, living and governance (Giffinger and Pichler-Milanovic, 2007). They derive from knowledge-intensive creative strategies that have as a goal the improvement of the socio-economic, ecological, logistic and competitive performance of cities and rely on a mixture of human, infrastructural, social and entrepreneurial capital (Kourtit and Nijkamp, 2012). These investments in human, infrastructural (transport and ICT) and social capital promote sustainable economic growth and a good quality of life, via participatory governance and by intelligently managing natural resources (Caragliu *etal.,* 2011).

Definitions that do not include sustainability as one of the smart city strategic goals, view it as a city that utilizes ICT to create more interactive and efficient components and utilities of critical infrastructure (Azkuna, 2012). These components are suggested to be administration, education, healthcare, public safety, real estate, transportation and utilities (Belissent, 2010). Smart cities adopt scalable solutions that utilize ICT to boost efficiency, decrease costs and improve quality of life (CISCO, 2012). They will use communications and sensor capabilities embroidered into the infrastructure of the city in order to optimize electrical, transportation and other logistical everyday operations in order to improve the quality of life (Chen, 2010). Such technologies provide an interaction space between citizens, authorities, businesses and other actors, to become actively engaged in the design and planning processes (Batty *et al.,* 2012). While the definitions above derive from academic literature and government papers, similar themes can be observed in definitions deriving from industrial actors. IBM (2009) considers that a city can become smart by optimally using all the available interconnected information to comprehend and regulate its operations, and optimize the utilization of available resources. Accordingly, others support that a smart city can be built by integrating platforms, terminals and data, through policy, technology and capital, in an efficient way (Fiberhome Technologies Group, 2018). From a different point of view, ARUP (2011), views the smart city as a city with clear and transparent structure of its urban systems, which are simple, responsive and adaptable with the use of technology and design methods. In this city, citizens are encouraged to interconnect with their wider ecosystem and collectively engage with it.

In summary, while sustainability oriented definitions appear to focus on the performance of the environment, the economy, mobility, people, quality of life and governance, non-sustainability oriented definitions are particularly interested in the efficiency of transportation, education and administration. Despite the common characteristics sustainability related smart city definitions present, they also demonstrate a number of variations. Different smart city definitions may include different dimensions of sustainability as their goal. Furthermore, the prioritization of sustainability as a strategic smart city aim appears to vary between definitions.

Sustainability oriented smart city definitions

Sustainability oriented smart city definitions from the selected sources were analysed according to the dimensions of sustainability they explore, namely the environmental, the social and the economic dimensions. This categorization allows for thematic patterns to emerge. Looking first at definitions which consider all three dimensions, which we term 'holistic approaches', they view the "smartness" of a city as a "certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth" (Zygiaris, 2013). Such perspectives speak to the perception of smart city as green, interconnected, intelligent, innovating and knowledgeable, terms which themselves have been the subject of a number literature reviews. These attributes contribute significantly towards the development and sustainability of cities (Zygiaris, 2013). This "smartness" is embedded into the city operations and is based on the analysis, monitoring and optimization of urban, physical (energy, water, waste, transportation and others) and social (equity, governance, citizen participation) systems, through transparent and inclusive communication structures (ICLEI,

2017). Similarly, smart cities can be regarded as systems of humans, utilizing flows of energy, materials, services and capital to achieve sustainable economic development, resilience and high life quality (EIP-SCC, 2013). In order for smart cities to achieve these goals, equitable, participatory, sustainable urban development policies will be needed (Thuzar, 2011). Interestingly, all sustainability oriented smart city definitions identified include a strong presence of the social dimension as well. When the concept of smart city was introduced, it was regarded as a strategic tool to underline the increasing importance of ICT and social and environmental capital in sculpting the competitiveness of modern cities (Schaffers *et al.,* 2012). Consequently smart city definitions that encompass the environmental dimension of sustainability frequently include the social dimension. Schaffers *et al.* (2012) support this view, arguing that this is due to the distinctive attributes that social and environmental capital can offer to smart cities compared to the "more technology-laden counterparts", frequently mentioned in the literature as digital or intelligent cities. Thus the distinction between digital or intelligent cities and smart cities appears to be the prevalence of the human element in the latter.

Indeed, numerous sources in the literature view sustainability in smart city as a predominantly social scope. The British Standards Institute (BSI) (2014), the national standards body of the UK, (BSI, 2014) supports the view that a smart city includes the efficient integration of physical, digital and human systems in the built infrastructure in order to create a sustainable, prosperous and inclusive future for its inhabitants. This emphasis on the habitability and inclusivity of the urban environments particularly underlines the social nature of smart cities. In other words they strive to improve city services and urban management for the citizens, by creating a socially advanced environment. The ultimate goal of these processes is improving the sustainability and liveability of the city (Toppeta, 2010). Through these definitions it can be observed that the combination of the human capital with technology can have an effect on urban services, city services, local actor interaction and quality of life, thus improving the social aspect of urban environments.

The identified literature includes few definitions that focus solely on the economic aspect of sustainable smart cities. Similarly to the environmentally oriented definitions, the economic oriented consider smart cities as cities that combine hard infrastructure with social capital, community institutions and technologies, but with an alternative purpose: that of boosting sustainable economic development and creating an attractive business environment (BIS, 2013). According to this approach, economic competitiveness along with environmental sustainability and general liveability become increasingly driven by ICT (Alcatel-Lucent, 2011). In the case of Singapore, the smart city has been defined as a local entity that holistically employs ICT and real-time analysis to promote sustainable economic development (IDA, 2006). Barcelona considers smart city as a sustainable, greener, highly-technological city with competitive and innovative commerce, and an enhanced quality of life that creates connections between people, information and urban elements, through the use of new technologies (Bakici *et al.,* 2012). This approach is a less theoretical and more practical one, where the need for sustainable development is recognized along with the need of the city to grow and flourish economically, through the combination of both hard and soft elements. However it is not clear if economic growth and enhanced quality of life are causally related, with economic improvement leading to better quality of life, or if these two goals should be

independently pursued. In addition to variations in content, sustainability oriented definitions present a discrepancy in the prioritization of sustainability as a smart city goal. In numerous of the definitions presented, sustainability is regarded as one of the primary goals of smart city, along with liveability. Respectively, approximately one third of the definitions presented, feature sustainability as one of the secondary goals in smart cities along with liveability, efficient use of resources and governance. Three definitions present sustainability as a tertiary goal, diminishing its importance in the smart city agenda. The primary goal in tertiary definitions is the quality of life and governance.

DISCUSSION

Sustainability oriented smart city definitions present some emerging themes that consistently appear in the literature. The themes are: the relatively anthropocentric focus of sustainability oriented approaches, the prevalence of result-focused definitions and the role of technology as a facilitator. They are related to the use of soft and hard capital, where soft capital is considered as human capital and societal structures and hard capital as the city infrastructure and material resources, combined through diverse technologies, with the purpose of enhancing environmental aspects of the city, boosting the economy and ensuring a high quality of life. In contrast, non-sustainability related definitions particularly highlight the importance of ICT in order to optimize the performance of the city and the use of resources, while the ultimate purpose of enhancing the quality of life remains unaltered. The variation to emerging themes between the two types of definitions demonstrates how the first type combines soft capital (the human and societal element), to hard capital (city infrastructure) while the second one focuses on the efficient utilization of resources through the use of ICT, thus underpinning the importance of hard elements. This can be specifically observed in definitions provided by technologically related industrial actors (CISCO, IBM and Fiberhome Technologies Group). Contrastingly, other actors in the ICT industry such as Hitachi (2012) and Schneider Electric (2014) provide more sustainability oriented, holistic definitions. This may be due to the fact that these firms are not solely ICT based but have a diversified portfolio that ranges from power and automotive systems to social infrastructure. In a similar alignment of sector and definition, ARUP a company related to the built environment define smart city as an urban system with structures focused on citizens and their neighbourhood, underlining the urban aspect.

Additionally, it can be observed that sustainability oriented definitions appear more results based, with non-sustainability oriented definitions more process based. Most sustainability oriented definitions highlight the results that smart cities aim to achieve answering to "why a city should be smart", while the non-sustainability- oriented definitions appear to answer to "how these results can be achieved", through expanding on the integration of different kinds of resources, such as human and infrastructure capital, in order to arrive to the smart city goals. This is furthermore noticeable in the role of technology, which in the first approach comes across as a facilitator to an end result, while in the non-sustainability oriented approach technology takes a more prominent role. Holistic approaches take into consideration all sustainability dimensions, the environmental, the social and the economic, and present a rather balanced point of view on what a smart city should be. Environmentally oriented definitions, which include the social dimension as well, support the cause of reduction of the

environmental impact of urbanism, the enhancement of life quality and the efficient use of resources as the smart city goals. These may be achieved through the use of technology in almost all definitions. This approach emphasizes mitigating the impact of cities on the environment and rarely takes into account the economic growth or development of the city.

Similarly, social sustainability-oriented definitions demonstrate how smart cities integrate technology with governance to improve the sustainability and liveability of the city. In contrast to socially oriented definitions, -those focused on the economic dimension of sustainability propose the combination of hard infrastructure and soft capital with the purpose of creating competitive cities and boosting sustainable economic development. A prevalence of socially related elements may be observed in smart city sustainability-oriented definitions. This is contrary to the urban sustainability literature where frequently the societal factor is overlooked or shadowed by the ecological aspect (Lehtonen, 2004). This phenomenon is extended to urban sustainability assessment (Berardi, 2013). Nevertheless, the human nature of urbanization and the social issues that rapid urban growth has caused, such as social inequality (Kim and Han, 2012), social deprivation, community disruption, public safety and health decrease (Bibri and Krogstie, 2017) have underlined the importance of the social aspect of smart cities and appear to have had a significant impact on the way in which scholars, organizations and industries define the term. On the other hand, a low number of definitions that take economic sustainability into account can be observed, which is contrary to the common connection between social and economic sustainability, frequently referred to as "socio-economic", indicating the strong connection between these two elements.

It is apparent that the diverse sustainability-oriented definitions of smart city do not view the goal of sustainability equally. Most definitions that take a holistic approach appear to view sustainability as one of the primary city goals. Interestingly, this is not the case for socially oriented definitions which focus more on quality of life and development or efficient use of the human capital, thus view sustainability as a desirable attribute, but has secondary or tertiary priority. This raises questions as to what trade offs the latter are willing to make in order to achieve quality of life over the preservation of the environment, as well as to what the cost of this trade off will be. Additional concerns are raised by the fact that no definition provides an explanation of what they mean by quality of life, what it incorporates and how it is defined. Undoubtedly, quality of life has different meanings for different parts of the world, as access to food, clean water and medicine as well as equity and equal opportunities are still an on-going problem in numerous parts of the globe. Nevertheless, regardless of the number of sustainability-driven smart city definitions and its apparent high priority as a goal, some authors pose questions regarding the true impacts of smart city on ecological sustainability. One of the issues arising is the potential psychological disconnection of citizens to the environment and disruption of the relationship of citizens with nature due to overexposure to technology (De Jong *et al.,* 2015). Additionally, some authors dispute the net contribution of smart cities to sustainability (Salvati *et al.,* 2013) (Viitanen and Kingston, 2014) and are supported by the findings of De Jong *et al.* (2015)'s network analysis of smart city concepts, which indicate a distance between the sustainable and the smart city. Whether these concerns are valid or not, largely depends on the way in which the smart city model is or will be embedded in a city's system, and the strategies and main goals that the authorities have set for the city, as well as the resources that will be used in order to achieve it.

CONCLUSIONS

This comprehensive literature review identified a number of emerging themes in smart city definitions. Sustainability oriented definitions often focus on the combination of soft capital, such as human and social capital, and hard capital, a city's physical infrastructure, in order to deliver a sustainable, liveable and efficient city. On the other hand, non-sustainability oriented definitions usually highlight the importance of ICT utilization to efficiently combine resources that will make the city more interconnected, intelligent and liveable. Holistic approaches cover all sustainability dimensions, the environmental, the social and the economic one, and present a balanced point of view on what a smart city should be. Most environmental and social dimension focused definitions focus on how smart cities integrate technology with governance to improve the quality of life and reduce the environmental impact of urbanism. Diversely, economic oriented definitions propose the combination of hard infrastructure and soft capital with the purpose of creating competitive cities and boosting sustainable economic development. Interestingly, in contrast with most sustainability related literature, the social dimension of sustainability appears to be the prevailing one in smart city definitions. It is concluded that a number of the existing definitions take into consideration all salient aspects of urban sustainability in the literature. These are provided by Giffinger et al. (2007), Kourtit and Nijkamp (2012) and Zygiaris (2013). These definitions present a balanced view between the environmental, the economic and the social aspect of smart city and are recommended as comprehensive definitions in which sustainability is afforded a primary role.

Further research on the contribution of smart cities to achieving sustainable development is essential. As this research indicated, one of the main goals of smart city initiatives is the improvement of quality of life, yet no definition explained what this means and at what cost this "improvement" will came for the society and the environment. Thus, future attempts to define smart city should take the cause-effect relationship of improvement of quality of life through the use of modern technology into consideration and truly reflect on whether all dimensions of sustainability are equally represented.

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SUSTAINABILITY IN THE NIGERIAN BUILT ENVIRONMENT – A SCOPING STUDY REVIEW

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Abstract

Sustainability is not new concept; however, it has received increased attention because of the effects of anthropogenic activity in varied sectors of life. The built environment is one of such sectors, which is often criticized for its effects and as evident in literature, sustainability in the built environment is complex in nature. As such, the interpretations associated with it, the significance attributed to it and its adoption, are diverse in every country. Sustainability in the built environment is important, as it promotes energy friendly and efficient systems in buildings, especially in light of global climate change. However, this appears to be lacking in the Nigerian built environment. The paper aims to examine impeding factors to sustainability in the Nigerian built environment through a scoping study review. Nigeria is often described as a paradox in many ways, one of which is having a power deficit and yet abundant renewable energy sources. The paper presents a comprehensive survey of relevant literature on the perceptions of built environment professionals in Nigeria for identification of impeding factors to sustainability adoption. While impeding factors to sustainability in the Nigerian built environment is not new, the identification and understanding of the factors remains restricted and shallow. As such, it lags the required uptake for sustainable buildings reflective in other countries. In addition, a comprehensive survey of impeding factors to sustainability in the Nigerian built environment is lacking in literature, to the best of the researcher's knowledge. The paper aims to fill this gap through a scoping review, underpinned by Daudt et al.'s (2013) adapted version of Arksey and O 'Malley's (2005) five stage framework. The main findings suggest that the Nigerian context have not been holistically embraced in existing studies, highlighting generalised impeding factors such as finance and awareness as top ranking factors. Furthermore, the review addresses concerns associated with the existing research approach and its shortcomings, as well as strategies for improvement. Further research to expand knowledge is also recommended.

INTRODUCTION

The rapid changes in the global landscape have been attributed to population growth and development (industrialisation), which has led to increased infrastructural and other demands (IPCC, 2014; Zuofa and Ochieng, 2016). Infrastructural development has been described as the foundation of every society, as it is essential to meeting populations demands and sustained growth (Heravi et al., 2015; OECD, 2001), with the cconstruction industry being central to this, as it is responsible for delivery of development; producing buildings and the built environment. As such, the built environment has been identified as both the solution and the problem (Heravi

et al., 2015). As evident in literature this is a significant volume of research on the problems and solutions of the built environment, from varied perspectives such as, climate change, sustainability, etc. (Heravi et al., 2015; Mao et al., 2009). Nonetheless, there is still the need for further research on sustainability in the built environment and its impact on construction projects, especially in developing countries, which du Plessis (2007) and Zuofa and Ochieng (2016) highlight as indispensable for the establishment of sustainable practices specific to their context, especially with accelerated urbanisation and infrastucutal development. In addition, from a building professionals perspective.

The challenge – climate change

The effects of anthropogenic activity in varied sectors of life has given cause for global environmental concern (IPCC, 2014), which has propelled widespread development and implementation of combative sustainable measures (IEA, 2016). The built environment is one of the sectors often criticised for its effects due to its activities, with buildings accounting for 40% of global greenhouse gas (GHG) emissions due to high-energy consumption (IPCC, 2014). As such, the IPCC (2007) rates the building industry having the highest GHG emissions, with the potential to increase to 70% in 2030 and double in 2050 if the current trends persist (Stern, 2008). Usman and Mohd (2012) describe building practices as showing little regard to the environment and as simply put by Dalibi et al. (2017), "…the friendliest way to handle the environment is not build." (p.1). Although this may be beneficial to the natural environment, Tam, et al. (2004) note it will be detrimental to the needs of the people who inhabit it.

The built environment consumes a vast amount of natural resources and produces a lot of waste, causing harm to the wellbeing of people and the environment and will continue to do so, if not properly managed (Emmanuel et al., 2014; Joachim et al., 2015; Klein et al., 2009). This both Emmanuel et al. (2014) and Joachim et al. (2015) opine will have far reaching implications on growth and continued survival of people. Abolore (2012) notes that the built environment provides a platform where environmental, economic and social issues meet, which is significant in every society. Consequently, it is important that due consideration is given to design and construction of buildings and their surroundings, as it informs resource use and management over its lifetime (Prasad and Hall, 2005), which is invaluable for sustainable human development. It is therefore essential, given the impact human activity has on the environment, any building which accommodates human activity must contribute to climate change mitigation, by ensuring a healthy, safe and productive environment for people, otherwise, it is harmful (Papesch et al., 2011). This is however not the case with developing (African) countries, which often face fundamental social, economic and infrastructural challenges such as, poverty, limited access to electricity, water and food shortage, poor sanitation, poor healthcare, lack of education, etc. (UNESCO, 2016; Usman and Mohd, 2012). In addition to administrative and institutional problems (Abolore, 2012; Ojelabi et al., 2017). Usman and Mohd (2012) note that environmental aspects such as sustainability are regarded as a luxury in such environments.
This is a major concern, as the need for sustainability is undisputable to the sustained growth and development of developing countries (Olorunfemi and Adebimpe, 2008; du Plessis, 2002; Rowlands, 2011). Rowlands (2011) notes that, the very nature of developing countries, especially in sub-Saharan Africa (SSA) connects them to climate change due to their lack of emission targets and/or commitments, minimal GHG emission contributions and being

impacted by global climate change. Nigeria is a developing country in SSA, which typifies this scenario, with a history of significant disruption to its natural and built environment notably pollution, flooding, fires, waste generation, and building collapse (Ede, n.d.; Ojelabi et al., 2017). The country has struggled to achieve sustainable practices in its built environment (Abolore, 2012).

The solution – sustainability in the built environment

Sustainability is not a new concept and although it has generated significant interest in the wake of climate change, it came into prominence in the 1987 Brundtland Commission Report (WCED), 1987), which provided a basis for understanding sustainability in the context of construction (Nwokoro and Onukwube, 2011). Consequently, sustainability has been regarded as the solution to meet both societal demands for development and the environmental need for stability; striking the required balance for sustainable human development (Bourdeau, 1999; IPCC, 2007). The IPCC (2007) identifies sustainability through the integration of renewable energies and reduced energy consumption in buildings as two ways to achieve climate mitigation. According to Abolore (2012), sustainability in construction is about ensuring the adoption of practices for reduced environmental burden of projects and encourage ecologically friendly buildings. In doing so, improving the environments resilience and ability to protect itself against the adverse effects associated with construction activities (Dalibi et al., 2017).

As discussed in preceding sections, appreciation for sustainability has attracted interest and generated significant research (Ahn et al., 2013; Bond, 2011; Cooke et al., 2007; Darko et al., 2017; Djokoto et al., 2014; Painuly and Fenhann, 2002; Rupf et al., 2015). This is of no surprise, given the multidimensional nature of sustainability and the multi-disciplinary context of the built environment (Amaratunga et al., 2002; Zuofa and Ochieng, 2016). As such, the interpretations associated with it, the significance attributed to it and its adoption are country specific. Consequently, the approach to sustainability is not a "…one size fits all." OECD (2001, p.2). The study by Darko et al. (2017) presented a global perspective of the influencing factors to green building (GB) integration, primarily focusing on OECD countries, whilst the studies by Ahn et al. (2013), Cooke et al. (2007) and Djokoto et al. (2014), presented country specific perspectives from USA, UK and Ghana respectively. Painuly and Fenhann (2002), presented a comparative perspectives between countries in Africa (Egypt, Ghana and Zimbabwe). The studies above and others, reveal the need for sustainability as the mitigating and corrective element in the construction industry (Iwaro and Mwasha, 2010; Otegbulu et al., 2011). As such, there is a pressing need to implement efficient measures to manage resources in the built environment (Iwaro and Mwasha, 2010). One such measure, is environmentally friendly buildings (green or sustainable) (Painuly, 2001), which has seen the establishment and growth of green building councils (GBC's) and standards worldwide (WGBC, n.d.).

Green buildings are known to promote resource efficiency throughout the lifecycle of the building, are sensitive to human impact, improve building performance, and co-exist responsibly with the environment (Dalibi et al., 2017; Lockwood, 2006), which Lockwood (2006) opines has contributed to its spread. In addition to encouraging competitiveness, technologies and practices (Usman & Mohd, 2012). Although, GB standards have been embraced by many

countries, this has been limited to developed countries such as, the UK, USA and Canada (Oladokun et al., 2010). With the aforementioned countries having established GBC's and standards, notably in the UK, the Building Research Establishment Environmental Assessment Method (BREEAM) and in the USA, the Leadership in Energy and Environmental Design (LEED) (U.S.GBC, 2002). South Africa although classified as a developed country, is the only country in Africa with an established GBC and certification body; Green Star SA. Other countries such as, Kenya, Ghana and Zambia are currently in the process of developing such councils and standards (WGBC, n.d.). Nigeria, however, is yet to have a comprehensive sustainable strategy (Joachim et al., 2015), but has adopted LEED as a green standard on a voluntary basis (Usman and Mohd, 2012).

NIGERIAN BUILT ENVIRONMENT

Nigeria is often described as a paradox in many ways, one of which is having a power deficit and yet abundant renewable energy sources (Radhi et al., 2013; Uduma and Arciszewski, 2010). The has placed a strain on it natural environment due to the struggle of its construction industry to meet increasing demands (Africa Progress Panel, 2015; Olorunfemi and Adebimpe, 2008). This is evident in the countries environmental performance ranking of 100 out of 180 countries, based on human health and ecosystem protection (Yale University, 2018). Byrd and Leardini note, "to be sustainable, buildings should usually last for many generations" (2011, p.482). However, this does not appear to be the case in Nigeria, which Abolore (2012) attributes to the building process in the country. Ibid (2012), opines that the building process in Nigeria places little or no significance on sustainability, which has resulted in the challenges facing the built environment such as, energy efficiency, structural failure, overdesign, fires, flooding, etc. (Nwokoro and Onukwube, 2011; Ojelabi et al., 2017; Olurunfemi and Adebimpe, 2008).

Self-power generation

Energy plays a vital role in any society, creating a conducive environment for human development (wellbeing) and enhancing economies (UN, n.d.). Nigerians are well aware of the benefits and equally the challenges of energy and as such, have become seasoned and independent energy generators (Oseni, 2016; World Bank Group, 2014), necessitated on one hand by the country's erratic electricity supply from the national grid (Amankwah-Amoah, 2015). On the other hand, by the populace's fundamental need for daily operational continuity, personnel wellbeing, and property safety (GOPA-International Energy Consultants GmbH, 2015). Nigerians have sought alternative reliable sources of power supply in the form of diesel and petrol (fossil-fuelled) powered generators. As such, it can be argued that self-power generation has been the natural reaction to the situation; natural evolutionary process. The studies undertaken by Oseni (2016) and World Bank Group (2014) highlight the national power situation experienced by residences and businesses respectively, recording average daily durations of electricity outage of four and eight hours respectively. This resulted in significant disruption to routine household and business operations such as, loss of sales and reduced productivity, damage to equipment, loss of produce and the risk to human health and safety. Hence the countries overreliance of fossil-fuelled generators, as ease of access to reliable and affordable electricity has proved to be somewhat unattainable (Ibitoye & Adenikinju, 2007; Oseni, 2016). Self-power generation has become commonplace in the environment across all

sectors; federal, commercial and private (Federal Government of Nigeria, 2012; Oseni, 2016; World Bank Group, 2014), becoming the country's de-facto power infrastructure providing energy on demand.

As of 2014, the country had the lowest electricity consumption of 144 (kWh/capita) in Africa, and according to Awofeso (2011), 90% of businesses and 30% of residences in Nigeria have their own generating sets. Nigeria is the leading generator importer in Africa (GOPAInternational Energy Consultants GmbH, 2015), and it is estimated that over 60 million Nigerians own generators and spending over N1.5 trillion annually to fuel them (Ejiogu, 2013). This puts into perspective the potentially significant increase in GHG emissions from Nigeria, as it is already the second largest contributor of GHG emissions in Africa (CDIAC, n.d.). The IEA (2016) projects an increase in developing countries contribution to GHG emissions as they industrialize. Africa is already projected to have a 78% increase in energy emissions by 2025 (Stern, 2006).

Designing for generators

The building process in Nigeria is no different from that of other countries, which primarily comprises of design, construction, and operations. However, where it differs is the design stage (design process), which has seen an evolution or adaptation to meet the peculiarities of the environments of which an overriding aspect is energy. As discussed in the preceding section, self-power generation emerged as a necessary evil, and as such it became the primary energy supply to buildings and ancillary facilities alike (Bada, 2011). Consequently, generators and ancillary services and infrastructure are a prime consideration in all buildings from early on in the design process (Mu'azu, 2012), such that Mu'azu (2012) aptly describes is part of the vernacular architecture. This has had the effect of hindering the potential to consider alternative energy sources to power buildings. This is of significance, as most buildings in Nigeria are designed to be self-sufficient, providing their own services (water and sanitation) and infrastructure (borehole, water and sewage treatment plants) (World Bank Group, 2014) due to poor and inadequate service infrastructure. This results in increased energy requirement, contributing to the dependency on fossil fuels (Amankwah-Amoah, 2015), resulting in continued GHG emissions which causes environmental and public wellbeing problems (Awofeso, 2011; Oseni, 2016).

Energy efficiency

According to Bajare (2016), Nigeria is lacking in the incorporation of energy efficiency systems into its construction industry, which has resulted in its current GHG emissions. The study by Iwaro and Mwasha (2010), which sought to investigate sustainable energy efficient design in buildings in developing countries, identified Nigeria as lacking in building energy standards. They stated that this was due this was due to the deficiencies Nigeria's 2006 National Building Code. The 2006 National Building Code is the foremost statutory building guideline for design and construction in the country, and at present does not include any energy efficiency requirements for building professionals to refer to (Arup Nigeria, 2016). According to scholars, the lack of adequate guidelines has fostered an environment of unstructured design processes in the country (Otegbulu et al., 2011), resulting in poor planning and the development of buildings that focus on attaining an aesthetic value as opposed to functionality (Nwofe, 2014). The lack of energy guidelines is already evident in the country, with criticism of poor functioning

buildings and over design resulting in high-energy consumption in buildings, fostering an environment of privately owned fossil-fuelled generators (Iwaro and Mwasha, 2010). This environment has ultimately contributed to GHG emissions, as well as having a trickle effect on the utilisation of sub-standard equipment, with generators no exception (Otegbulu et al., 2011).

Building control

Ojelabi et al. (2017) attributes poor building control practices, resulting in and environmental problems as evidence of the lack of sustainability in the Nigerian built environment. Building collapse has become more frequent, raising concern about the practices in the construction industry, particularly as it has direct implications on human wellbeing (Otegbulu et al., 2011). As of 2017, there were over 50 reported cases of building collapse, resulting in a number of fatalities, with most collapses occurring in the major cities (Nnodim, 2017). The study by Fadairo & Ganiyu (2010), addresses the issue of lack of adherence to building setback requirements and inadequate draining provision, which has increased the vulnerability to flooding. This was reiterated by Otegbulu et al. (2011), who noted flooding as a major concern in Nigeria having both economic and environmental impacts due to poor planning and design. Otegbulu et al. (2011) also identified an overwhelming use of candles, which was linked to building fires. The studies discussed above, provide an overview of the status of the built environment in Nigeria. The studies reveal how vulnerable the built environment is as a result of unsustainable practices and dysfunctional systems, intended to protect and ensure its sustained development, however are doing the opposite. According to Ojelabi et al. (2017), "developments that do not consider health, welfare and quality of life should be discouraged" p.42. This further highlights the significance of having effective measures in place to ensure sustainability of the built environment. Ede (n.d.) notes that it is a natural process for the built environment in most countries to undergo transformations due to technological and other advancement. However, as other countries transformations have been positive, contributing to the sustained growth and development of its population and environment, this has not always been the case in Nigeria.

Despite the many challenges faced in the Nigerian built environment, it does not appear to have generated the required impetus for change, towards sustainable practices and environmental friendly buildings in the construction industry, albeit the evident need for it. Dalibi et al. (2017) refers to factors inherent in the Nigerian construction industry as impeding sustainability due to its snail's pace adoption of initiatives and practices aimed at ensuring environmental sustainability amidst the negative effects. This is of significance, in light of climate change challenges facing the global community and as discussed in preceding sections, Nigeria being a developing country is vulnerable to its effects (Gujba et al., 2012) albeit it not currently contributing significantly to it (IEA, 2016). The current practices in the built environment put Nigeria at risk of becoming a major contributor (Otegbulu et al., 2011), as such it is pertinent to address these issues now, as greater preparedness is required (Ede, n.d.). Therefore, the research aim is to investigate sustainability in the Nigerian built environment, with a particular focus on the impeding factors to its adoption.

IMPEDING FACTORS TO SUSTAINABILITY

Like most aspects of sustainability, there is a growing body of knowledge on impeding factors. A review of the literature identifies numerous studies, which have contributed to the discourse on barriers (challenges, obstacles, difficulties), as well as, revealing a shortage of information on developing countries (du Plessis, 2007; Serpell et al., 2013). Previous studies have tended to focus on developed countries. In addition, most of the studies adopted quantitative research strategies and methods (see Ametepey et al., 2015; Chan et al., 2016; Djokoto et al., 2014; Farkas et al., n.d.; Painuly, 2001; Pegels, 2010). For example, the studies by Chan et al. (2016) and IEA Task 41(cited in Farkas et al., n.d.), sought to investigate barriers to adoption of GB technologies and the integration solar thermal and photovoltaics (PV) by international experts and professional respectively. However, both studies confined their sample population to developed countries, as well as adopting surveys (questionnaires) for data collection. The studies by Ametepey et al. (2015) and Djokoto et al. (2014), which were undertaken in developing countries, applied pre-defined frameworks from existing literature for identification of barriers and utilised surveys to rank of barriers.

Barriers in literature have been broadly categorised into six aspects, namely economic/financial, institutional/government, attitude (social/cultural) and market, technical/technological, and awareness/knowledge and information (Chan et al., 2016; Painuly, 2001). However, it is important to note that the barriers and categories are based on studies developed countries, which have developed frameworks for identification of barriers and have been adopted in studies undertaken in developing countries. Thus, their level of applicability to developing countries has been questioned, generating discussions (Katikiro, 2016; Plessis, du, 2007; Trevarthen, 2011; Ugulu, 2016; Unuigbe et al., 2017). However, the pre-defined frameworks are widely used in studies in developing countries to determine the top ranking barriers within the developing context, which limits and directs the barrier focus. Trevarthen (2011) notes that much of the research undertaken in developed countries focus on economic and technical aspects relating to sustainability, with limited research on social or cultural aspects. The latter two, which are an inherent in the context of developing countries in SSA, Nigeria being one of such countries. This is evident in the studies above (Ametepey et al., 2015; Djokoto et al., 2014), which identified financial and technological barriers as the top ranking barriers to sustainability adoption.

Unuigbe et al. (2017) argue that the use of pre-defined frameworks and quantitative strategies present generalised and non-context specific barriers when applied to developing countries, which will have an impact on sustainability adoption (du Plessis, 2007). Thus, the studies fail to provide the required insight essential for informed development and implementation of sustainable strategies suited to developing countries context for sustainable development (du Plessis, 2002; 2007). For instance, the study by Ugulu (2016), highlighted concepts such as, self-help which is steeped in the social, cultural and economic fibre of SSA countries, but is unfamiliar to developed countries. The provides justification for undertaking a study in Nigeria, as the barriers identified in developed countries do not take into cognisance social, cultural and other characteristics and factors inherent in developing countries. This will undoubtedly influence the perceptions of people, as well as the significance attributed to it and consequently the level of sustainability adoption. It will also enable the identification of specific barriers that

impede these practices for informed development and implementation of strategies for sustainable development. In addition, Darko et al. (2017) and du Plessis (2007) advocate further detailed research in developing countries such as Nigeria, due to its fast changing landscape as a result of population growth, development and challenges presented by climate change.

RESEARCH METHODOLOGY

The study is based on a scoping study focusing on relevant past empirical studies on impeding factors to sustainability in the Nigerian built environment. Scoping studies have been conducted in varied fields such as, health (Davis et al., 2009), education (Forsman and Vinnerljung, 2012), construction (Radhi et al., 2013) and economics (Olawale et al., 2008). The studies have shown to provide rigor, replication, validity and transparency in their approach to literature review, informing on subject matter and identifying knowledge gaps (Levac et al., 2010; Daudt et al., 2013). The scoping study is underpinned by Daudt et al.'s (2013) and utilises an adaptation of Arksey & O 'Malley's (2005) five-stage framework. The adaptation includes as additional stage to assess the quality of the studies, which will offer consistency and methodological rigour. The six stages include: identifying the research question, identifying relevant studies, study selection, assessing quality of papers, charting the data, and collating, summary and reporting results.

Scoping Study Process

The study follows the scoping review process as shown in Figure 1. The search focused on identifying studies based on empirical evidence of the perception of sustainability in the Nigerian built environment, such as barriers or obstacles or challenges. As the search was intended to be comprehensive, it was important that is was informed by an initial question, being the first stage of Arksey & O 'Malley (2005) framework. The question that was posed was 'what does literature tell us about the factors impeding sustainability in the Nigerian built environment?' This question was intended to capture literature around the subject area and enable identification of relevant studies using key search terms (second stage), as shown in Table 1. The primary search sources were electronic databases and a manual search of reference lists on publications based on a two-phase inclusion and exclusion criteria (stage 3) as shown in Table 2. The inclusion and exclusion criteria were developed based on imposed limitations, to ensure only relevant studies were identified, as well as, effectively managing the amount of studies found due to time and resource constraints (Unuigbe et al., 2017). This is evident from the volume of studies generated (68,910) based on the initial key search terms.

Table 1, Search Strategy – Key search terms

Search Strategy – Key search terms	
	1 sustainab* AND (environment* OR energy efficien* OR green) AND (built environment OR construction industry) AND building? AND (perception OR awareness) AND (barriers OR obstacles OR challenges) AND nigeria
	2 sustainab* AND (renewable energy or alternative energy or green energy) AND (environment* OR energy efficien* OR green) AND (built environment OR construction industry) AND (sustainable construction OR sustainable building OR green building) AND Nigeria AND perception AND barriers
	3 (sustainab* OR eco-friendly OR green) AND (built environment or construction industry) AND nigeria AND (perceptions OR barriers)

The search was limited to peer-reviewed journals published in English in the last eighteen years conducted on Nigeria or which included Nigeria. Four databases were used for the electronic search; Leeds Beckett University database (Discover), Google Scholar, Scopus, West Africa Built Environment Research (WABER) Conference and The British Library thesis search engine, e-theses online service (EThOS). A manual search of references involved the review of bibliographies of publications identified through the database search, which proved useful in identifying further literature. However, due to practical limitations, there had to be a limit placed on the searches. The first phase of the inclusion and exclusion criteria limited the search to time-period, language and publication type, which significantly reduced the number of studies identified. In addition to these restrictions, studies deemed not relevant such as, articles specifically relating to issues on health, education etc. and duplications were excluded following a review of the abstracts.

Table 2, Inclusion and Exclusion Criteria

Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Time period	2000 – 2018 – due to the evolving nature and development of the field	Studies before 2000
Language	English	Non-English (Foreign language studies)
Type of article	Published peer-reviewed (scholarly) journal and Doctorial research	Articles that are not academic journals or Doctorial research
Geographic focus	Studies carried out on Nigeria or which include Nigeria	Studies related to other countries
Literature focus	Studies with overwhelming themes that relate to perceptions and/or awareness of sustainability in the Nigerian built environment or construction industry and/or buildings in Nigeria	Studies which make a passing reference to perceptions and awareness sustainability
Study focus	Studies which provide empirical arguments/evidence of perceptions and/or awareness by stakeholders	Studies based on perceptions and/or awareness based on literature review or on country accounts

The second phase guided the final review and selection of nine relevant articles, which were downloaded into the reference manager, Mendeley for review of full text. Figure 1, outlines the review process. The studies are limited in number as a significant number of studies identified in the literature were purely based on literature review and/or country accounts.

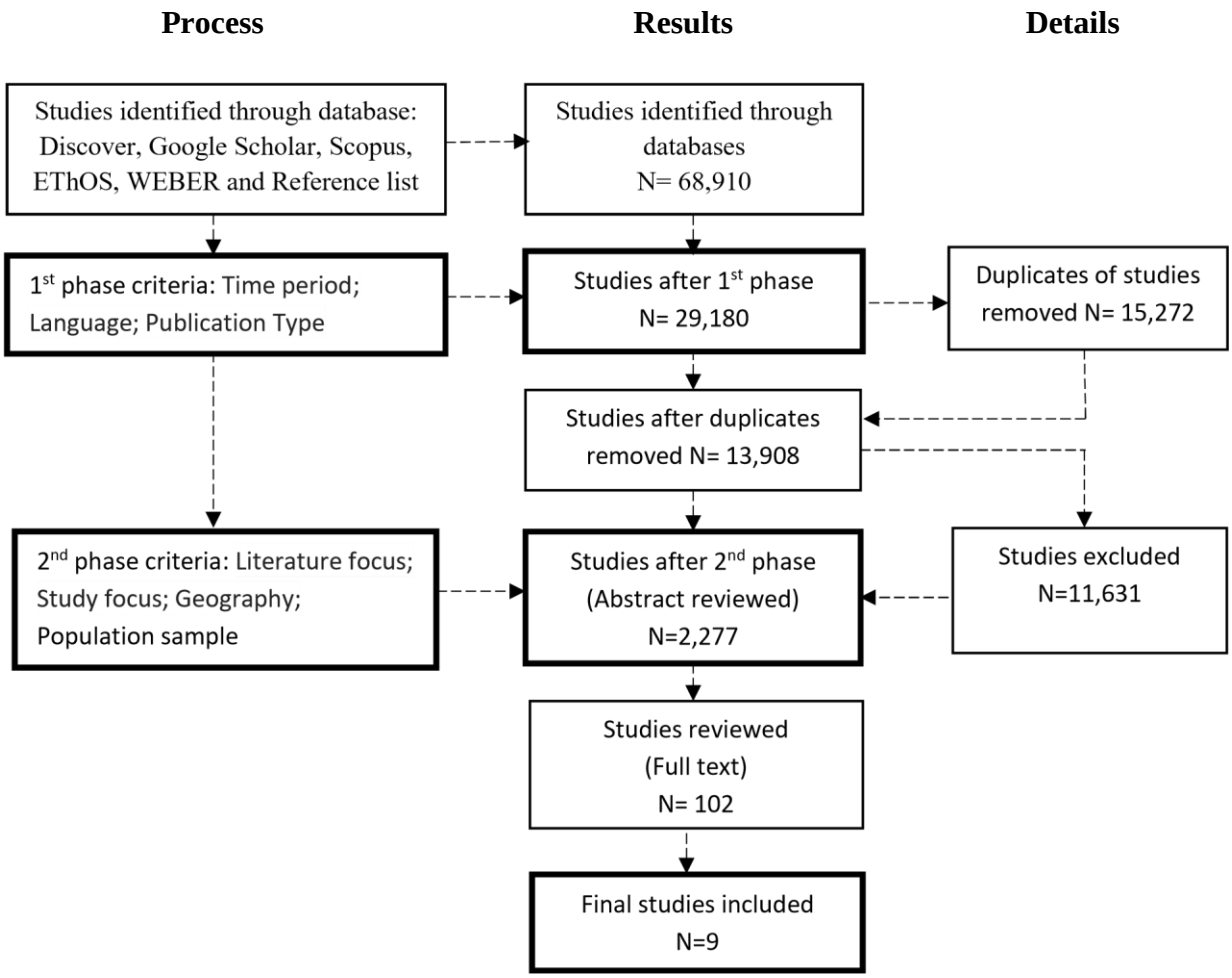

Figure 1. Scoping Review Process

The fourth stage required the quality assessment of the nine studies, which has been a criticism attributed to Arksey & O 'Malley's (2005) framework as it presents no basis for determining this in the studies selected (Levac et al., 2010; Daudt et al., 2013). Hawker et al.'s (2002) assessment protocol was used, providing a structured framework for assessing studies based on similar criteria. Thus, excluding bias and ensuring transparency and rigour throughout the selection process. This was important, as it ensured basic standards were met across all studies, it checked the suitability of the study under review and assessed the value/contribution of each study. The protocol was based on a 4-point scoring system, ranging from 1 (very poor) to 4 (good) and intended to present an indication of the strength/weakness of the study by rating each study across nine aspects; abstract and title, introduction and aims, method and data, sampling, data analysis, ethics and bias, findings/results, transferability/generalizability and implications. The lowest and highest, possible scores attainable being nine and thirty-six

respectively. Table 3, presents a summary of the total quality score attained with sub category scores by each study. It is important to note that not all studies provided sufficient information, as well as not properly presenting information in an accessible format.

The scores for methodological quality ranged from 20 to 34. The scoring system indicates that the studies are deemed to be of a moderate to high quality. All studies presented relatively clear statements of the research aim and design. Not all studies provided clear justification of sampling; however, data collection and analysis processes were generally clear in all studies. The study by Allu and Ebohon (2014) was the only study that did not discuss data analysis processes. The findings of each study were also generally clearly presented and discussed. A major observation from all studies is the lack of ethical consideration and researcher bias. Only one study out of the nine assessed, addressed it some detail (Zuofa and Ochieng, 2016). Zuofa and Ochieng (2016) was also the study judged to be of high quality. It employed a qualitative research design using coding and NVivo software to aid in the analysis. It was also detailed, providing justification and an in- depth description of the analysis process.

Table 3, Quality Assessment Protocol with studies

	First Authors name								
Protocol	**Ojelabi (2017)**	**Dalibi (2017)**	**Zuofa (2016)**	**Bajare (2016)**	**Emmanuel (2014)**	**Dahiru (2014)**	**Allu (2014)**	**Abolore (2012)**	**ıro(2011)**
Abstract & Title	3	2	3	3	3	3	3	3	4
Introduction & Aims	4	3	4	3	3	3	3	4	4
Method & Data	4	3	4	3	4	3	3	3	3
Sampling	3	3	4	3	4	3	2	3	3
Data Analysis	4	3	4	3	4	2	1	4	3
Ethics and Bias	1	1	3	1	1	1	1	1	1
Findings/Results	4	4	4	4	3	3	3	4	3
Transferability/Generalizability	3	2	4	2	4	2	2	3	3
Implications & Results	3	2	4	2	3	3	2	4	3
Total	29	23	34	24	29	23	20	29	27

Key: 1 – Very Poor 2 – Poor 3 – Fair 4 - Good

As all nine studies were deemed moderate with above average scores and were all included in the literature review, as they explored the barriers to sustainability in the Nigerian built environment across varied facets. The studies were subsequently recorded (stage five) according to key aspects of information similar to each study reviewed, allowing for a

standardised framework, as shown in Table 4, with the findings presented according to the most recent year of publication

Table 4, Summary of studies included in scoping study review

Summary of recent empirical studies on barriers to sustainability in the Nigeria Built Environment						
Study/ Author	Sample	Research aims/objectives	Methods	Analysis	Key finding (impeding factors)	Quality score
Ojelabi. R.A. et al., (2017)	61 built environment professionals	Examine effectiveness of building control practices, and factors limiting the capacity of building control practices	Questionnaire	Mean item score; Percentage; ANOVA	Corruption; bureaucratic process and lack of coordination among agencies	29
Dalibi, S.G. et al., (2017)	480 built environment professionals	Identify, examine and assess factors hindering green building development	Questionnaire (hand delivery)	Mean item score; T-test	Perception of GB as expensive concept; unavailability of local GB materials and high cost of imported GB materials; and divergent views of success factor and criteria of GB development	23
Zuofa, T. & Ochieng, E. (2016)	25 project managers	Assess awareness and attitudes towards sustainability and identify barriers to integration of sustainability during practice	Semi - structured interviews	NVivo	Lack of awareness; limited trained personnel; perceived high cost; unclear guidance; limited leadership and organizational support; client requirements and influence and resistance to change	34
Bajare, P. A (2016)	80 owners, developers and built environment professionals	Examine awareness of sustainable development issues, policies and constraints limiting involvement development.	Questionnaire	SPSS version 21;Frequencies; Percentages	Lack of government support; lack of relevant building codes & standards and lack of understanding of integration approach of green concept in the building process	24
Emmanuel et al., (2014)	100 built environment professionals	Assess perception of sustainability performance of infrastructure projects	Questionnaire	Weighted mean average	Lack of ozone protection; modular and standardised design and discharge of water	29
Dahiru, D. et al., (2014)	50 lecturers and built environment professionals	Investigate problems and prospects of Green construction practice	Questionnaire; Interview	Mean percentage	Lack of awareness; lack of enabling environment to encourage use of GB; and economic situation of the country	23

Allu & Ebohon (2014)	36 built environment professionals	Investigate Knowledge and awareness level, current practices and improvement to practices	Face-to-face Interview	Not indicated	Low level of sustainable information, knowledge and awareness.	20
Abolore, A.A. (2012)	120 built environment professionals	Investigates Nigeria and Malaysia perceptions of sustainability in building industry	Questionnaire	Pictorial form; Percentages	Lack basic understanding of sustainable construction; political will and awareness to construct sustainably; individual commitment;educational/institutional framework	29
Nwokoro, I. and Onukwube, H.N., (2011)	85 construction professionals , contractor and client.	Examine understanding of sustainable and green construction, current practices and challenges of sustainable construction	Questionnaire; Focus Group Discussion	Mean item score	Lack of consideration of energy efficiency; integrated design process; air quality; thermal comfort and site suitability in the planning and construction of sustainable projects	27

FINDINGS AND DISCUSSION

Adoption/diffusion of sustainability in developing countries is dependent of a number of factors. The study sought to investigate the impeding factors to the adoption of sustainability in the Nigerian built environment. This section presents an overview of the findings of the scoping study review, which identified nine studies. The studies are briefly discussed and exact details of studies are presented in Table 4.

The study by Ojelabi et al (2017) identified the primary barrier due to government failure to effectively ensure compliance and administer the appropriate corrective measures. This findings are consistent to previous studies (Bajare, 2016; Oladokun et al., 2010) which both identified attributed lack of political support and institutional framework by government as hindering adoption respectively. The study undertaken by Bajare (2016), however revealed an awareness and importance of sustainability amongst professionals to both built environment professions and the Nigerian economy, but its significance level was rated low. In contrast, the study by Emmanuel et al. (2014) showed that sustainability performance falls between moderate to high levels. Dalibi et al's (2017) identified barriers relating to cost and differing participant views on success factor and criteria of GB development. However, the study identified technical knowhow as one of the least hindering factors, presenting a differing perspective to the findings of previous studies (Ashiboe-Mensah et al., 2011). The study by Zuofa & Ochieng (2016), highlighted differing participant understanding and lack of holistic adoption of sustainable practices during the building process as primary barriers, which added to the problem.

The study by Dahiru et al (2014) revealed that GB is currently not practiced, but there is a need for it exist. The main hindering factors were highlighted as lack of awareness and lack of an enabling environment in the country. This is in contrast to the studies by Bajare (2016) and Dalibi et al. (2017), which identified awareness as the least hindering factor. It was interesting

to note that the hindering factors adopted in this study varied from those adopted in Dalibi et al. (2017) both in number and in specific hindering factors. The only similar hindering factors adopted by both studies were awareness, technical knowhow and cost. The Allu & Ebohon (2014) study highlighted limited knowledge of the relationship between buildings and climate change. This is consistent with the findings of Abolore (2012) and Nwokoro & Onukwube (2011), which showed sustainability still at the very early stages, and as such, was not understood holistically.

Based on the findings, the two major barriers identified were cost and awareness/knowledge related, with the two least identified barriers being attitude, and institutional related, as shown in Figure 2. According to Chan et al. (2016), financial and awareness barriers are the two most cited barriers found in literature. The studies also highlighted an overwhelming adoption of quantitative research designs using questionnaires as the primary method for data collection. In total seven studies used questionnaires as their primary data collection method, this included two mixed method studies. Two studies used interviews for data collection. Figure 3, presents the methods adopted. In addition, seven studies adopted pre-defined frameworks and barriers identified in existing literature as the basis for developing their survey instrument. This explains the similarities and differences in barriers identified and raises concerns of researcher bias in inquiry, as selection of barriers precede and informs surveys. Thus, it can be argued that the outcome is somewhat predetermined as it limits the possible choices.

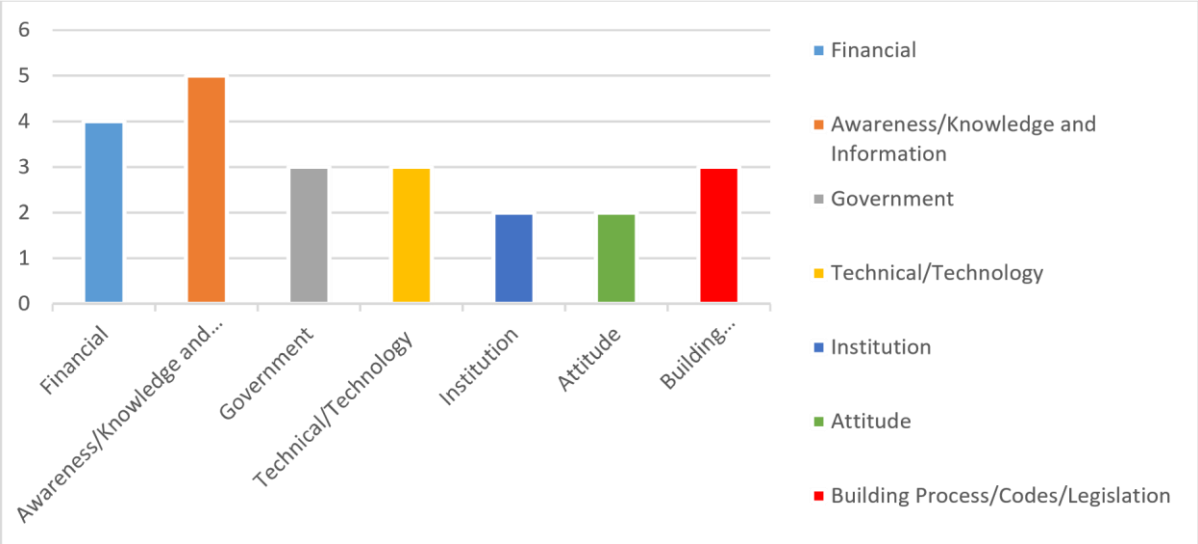

Figure 2. Overview of barriers (based on barriers in literature and predefined framework)

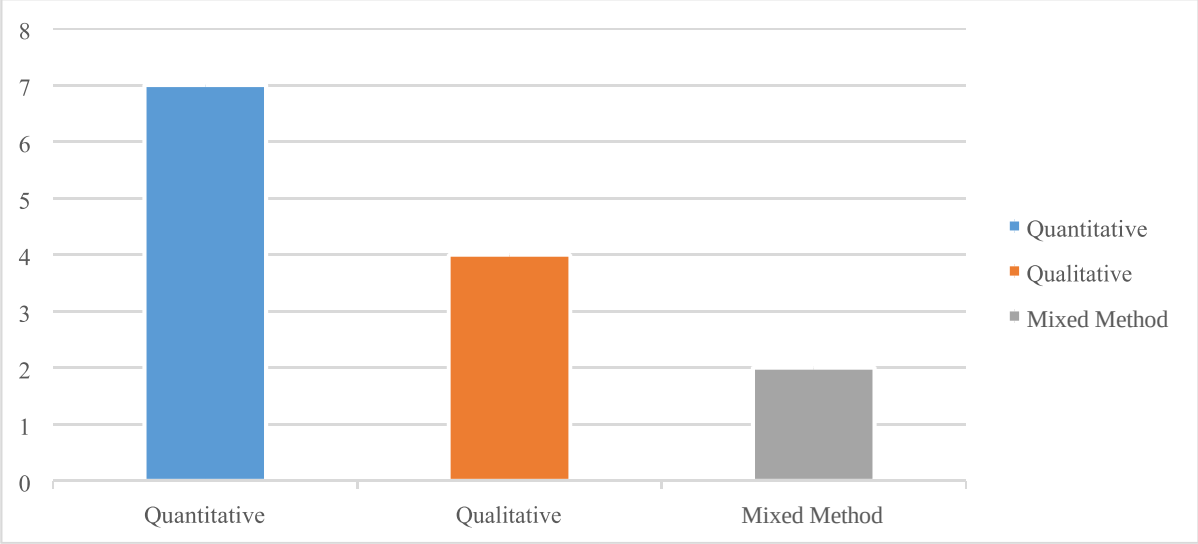

Figure 3. Methods adopted

CONCLUSION

Nigeria as a developing country has faced with a history of challenges in achieving sustainable developments and with the current changes in its landscape due to its rapid population growth, infrastructural development and global climate change, the need for the adoption of sustainable practices for sustainable development within its built environment is well past due. The utilisation of strategies and practices, which do not contribute to this, at best slows down the process for achieving sustainable development and at worst jettisons the process and leads to a catastrophe. The latter, which is not an option.

The purpose of the study was to provide a comprehensive overview of the available research on sustainability in the Nigerian built environment, with a focus on the barriers to its adoption. Nine studies were identified, representing a broad range of areas such as, performance of projects, building control practices, green buildings, sustainable construction, global warming and climate change, etc. from which barriers were identified.

The findings revealed that the barriers to sustainability in the Nigerian built environment are identified using predefined framework primarily informed by developed countries. As well as, adopting quantitative research approach, using surveys and descriptive statistics to elicit information from participants and analysis of data. Although the use of the questionnaires allowed for a large number of participants, according to Katikiro (2016) and Unuigbe et al. (2017), adopting a pre-defined framework limits the depth of results, by providing a narrow view, as it restricts the opportunity of participants to expand further on matters. In addition, the pre-defined framework provides a somewhat biased view, as it is based on what the researcher deems relevant, as opposed to the participants own views. Consequently, as the process to obtain data is pre-informed, so will the findings, and as such it is not fully representative of the contextual situation. Unuigbe et al. (2017) further notes that the limitations of the studies adopting pre-defined frameworks within the context of sub-Saharan Africa are based on the assumption that barriers are the same regardless of the context. However, there is evidence that this is not the case, as the diverse concepts, experiences and inherent complexities associated with developing countries, in particular sub-Saharan Africa,

are unknown and not understood in developed countries (du Plessis, 2007; Ugulu, 2016; Wilde, de and Coley, 2012).

Thus, it supports the need for further research adopting a qualitative approach using grounded theory method (GTM) as best suited to understand complex research phenomenon for deep insight of which sustainability in the Nigerian built environment presents (Amaratunga et al., 2002; Charmaz, 2007; Phelps and Horman, 2009; Unuigbe et al., 2017). Through the natural and heuristic approach offered by GTM, in-depth data grounded in context; taking into cognisance of its peculiar characteristics, which is guided by the experiences, perceptions and opinions of the built environment professionals. It enables the discovery of the human experience, exploring more fully the impact significance of sustainability and the relationship between building professionals and the environment. In addition, GTM is applicable in the context of sub-Saharan Africa (Unuigbe et al., 2017) as opposed to using predefined frameworks.

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CSR and Management

PERCEPTIONS OF SAFETY OFFICERS AND CONSTRUCTION MANAGERS ON MEASURES FOR EFFECTIVE IMPLEMENTATION OF ENVIRONMENTAL SUSTAINABILITY DURING CONSTRUCTION

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Keywords: Construction Manager, Construction industry, Environmental sustainability, Measures, Safety Officer

Abstract

This study aims at investigating the perceptions of safety officers and construction managers on the effectiveness of measures put in place towards achieving environmental sustainability in construction projects. A qualitative research approach was adopted and purposively selected construction managers and safety officers involved in construction projects around the Western Cape Province were interviewed. Specifically, data was collected by means of semi-structured interviews and participants were directly involved in site construction operations. In total, four construction companies participated in the study. The findings revealed that both construction managers and safety officers play different roles in ensuring environmental sustainability on construction sites and they concurred on some of the measures that they put in place in their respective sites to ensure environmental sustainability. The suggested measures for effective implementation of environmental sustainability included environmental plan, waste management plan, environmental control plan, risk management plan, environmental assessment, soil erosion plan, and pollution prevention plan. The research concludes by recommending that a more detailed analysis on measures of ensuring environmental sustainability in construction is required. Moreover, attention should be focused on how the roles of both construction managers and safety officers impact the environmental sustainability in construction projects because, if one of the pillars of sustainability is weak then the system as a whole is unsustainable.

INTRODUCTION

Sustainability is one of the most vital concepts that the world is looking at, especially in developing countries. In fact, as the population increases this raises the need for constructing new infrastructures with available resources. With technology evolving, all these infrastructures must be developed as effectively as possible but without compromising the resources for the use of future generations. With South Africa being a developing country, the need for infrastructure projects is increasing as a result of the surge in population. Shen and Zhang (2011) indicate infrastructure are intended for delivery of basic needs and services such as provision of housing, sports facilities, roads and transport, schools and welfare infrastructures. According to Parris and Leiserowitz (2005), the more the projects increase in number, the greater one has to look into the concept of sustainability especially during the construction operations phase.

Parris and Leiserowitz (2005) emphasize infrastructures should meet the needs of the present generation without neglecting the ability of future generations to meet their own needs. Every construction site has key personnel and they all have significant roles they play to ensure overall success of a project. Opoku, Ahmed and Cruickshank (2015) suggest construction industry require leadership that can develop within each organisation a culture that supports and promotes the adoption of sustainable practices. Construction managers and safety officers are some of the key roles on these construction sites and even though their roles differ, they both have different perceptions on how construction activities are managed daily to ensure environmental sustainability. Ofori and Toor (2008) conducted a study on leadership in various organisations and the study suggests that leadership in every organisation should provide a collective vision, strategy and a way forward in achieving a common goal of sustainability. For every construction project, Resnick (1994) stipulates that environmentally friendly developments must be considered and ways of implementing them effectively should always be considered.

Opoku, Ahmed and Cruickshank (2015) believe that construction industry requires leadership that can develop a culture that supports and promotes the adoption of sustainable practices within each construction firm. Hence study aims to identify measures for effective implementation of environmental sustainability in construction projects, specifically comparing the perceptions of construction managers and safety officers.

ENVIRONMENTAL SUSTAINABILITY IN CONSTRUCTION PROJECTS

Importance of environmental sustainability in construction projects

Morelli (2011) defines environmental sustainability as a state in which the demands placed on the environment can be met without compromising its ability to allow all people to live well, meeting both the now and future needs. Foy (1990) explains that from an environmental standpoint, sustainability requires that current environmental activities do not disproportionately burden future generations. Whether one considers sustainability as an interaction between people and the ecosystem, there should always be an agreement that ensures the provision of clean air, clean water, and clean and productive land is foundational in as far as construction activities are concerned. Zhang, Yang, Zhu & Wu (2005) estimate construction operations and deconstruction activities of huge buildings consumes large amounts of energy, raw materials, and water which is about 20% of the energy consumed and carbon dioxide emitted. According to Shen (2007), the adverse environmental effects from construction activities including usage of energy, dust and gas emission, noise pollution, waste, misuse of water resources and consumption of non-renewable natural resources have not been thoroughly dealt with. For this reason, Zhang *et al.* (2005) opine that energy conservation, prevention of pollution, efficiency of resources is very important factors for environmental sustainable construction. A construction project consumes various environmental resources including soil, minerals, water, plants and animals in all their biological and genetic diversity. Hence, the environmental impact of every construction project must be considered. If the methods adapted in construction projects use a huge amount of non-renewable resources or generates a lot of waste, then the environment will be compromised. Environmental preservation must be valued, and it is crucial that the construction methods used promote ways

that cover up for the loss that is being made. In the study conducted by Foy (1990), statistics shows that the built environment accounts for 45% of total South African carbon emissions whereby 27% is from domestic buildings and 18% from non-domestic. Moreover, 72% of domestic emissions arise from space heating and the provision of hot water, 32% of landfill waste comes from the construction and demolition of buildings whereas 13% of products delivered to construction sites are being sent directly to landfill without being used. It is then evident that, without a sustainably productive environment, it would be difficult or impossible to expect a sustainable society

Role construction manager and safety officer in ensuring sustainability in construction projects

Construction managers have a significant role in ensuring delivery of environmentally sustainable construction projects. Roles of construction managers include the implementation of environmental management system; putting in place strategies for cost savings, and reduction of waste; and the implementation of waste management system. Gilbert and Lindholm (2018) advise that conducting regular educative meetings on environmental sustainable practices and objectives for all site workforces is also of great importance. Jaworski and Samanta (2006) support that these regular meetings influence collaboration and communication among stakeholders which could lead to progress in delivering environmentally sustainable construction project. However, construction managers and safety officers have different roles in construction sites. According to Robichaud and Anantatmula (2011), construction managers have the responsibility of conducting, planning and strategising meetings in order to ensure that project goals are met. Complementarily the primary responsibility of safety officers is to create a safe environment in construction sites; they also are liable for ensuring that construction workers follow established policies and safety regulations including environmental sustainability measures. Henceforth, construction managers and safety managers have complementary responsibility for ensuring the achievement of sustainable environment measures on construction sites.

Measures for effective implementation of environmental sustainability in health infrastructure projects

There are different ways in which construction activities impacts the environment. These various ways affect the site and its surroundings during and after construction therefore measures that ensure minimising these impacts to ensure environmental sustainability should be implemented. According to an article written by Wei-cheng, Yu-hao and Chung Hua (2018), some of the measures to ensure environmental sustainability is that construction firms should analyse and plan on how the project will deal with the materials waste generated during the erection construction and as well as ensuring water pollution and storm water runoff are directly connected. Wild (2016) highlighted some of the ways to promote eco-friendly building practices which included: design, use of low-impact materials, the reduction of construction waste.

Wild (2016) deduced that decisions made at the design stage of a building have a long-term impact on its environmental footprint and therefore must be considered carefully. Buildings which are well insulated need less energy to heat up and cool down. Once the building is operational, energy efficient electrical systems and water conservation practices decrease usage and cost. Architectural and Engineering firms are now responding to increased client and market demand for green buildings by providing better insulated buildings that use less water, include fewer toxic materials, incorporate natural ventilation and light as well as decreasing operational costs. Wild (2016) added that in the reduction of construction waste, construction management teams in various construction companies are exploring ways to reduce waste by developing construction waste minimisation programs. These programs include waste prevention programs, ensuring that materials are stored properly, reusing old materials and containers, and recycling when possible. They also avoid waste by planning and working with suppliers to return unused materials and empty containers, avoiding excessive packaging and using suppliers that use environmentally friendly materials.

METHODOLOGY

There has been limited research undertaken in South Africa with regard to environmental sustainability in infrastructure projects. As a result an exploratory research approach was adopted to investigate the perspectives of construction managers and safety officers on measures put in place for effective implementation of environmental sustainability in construction projects. The survey was conducted among construction firms who are registered with the Construction Industry Development Board (CIDB). Purposive sampling method was adopted to select four construction projects based in Cape Town. These projects were selected on pragmatic consideration that is their availability. Purposive sampling consists of handpicking purportedly typical or interesting cases. It is a useful sampling method consisting of receiving information from a sample of the population that one thinks knows most about the subject matter. According to Yin (2009) there is no ideal number of cases that should be undertaken. The primary data was obtained via semi-structured interviews administered to relevant parties involved in site operations including the construction management team and health and safety officers. A framework of questions for the interview was designed to gather information with regard measures in place towards the implementation of environmental sustainability in construction projects. Respondents were first informed of the focus of the interview prior to meeting. The verbal arrangement was thereafter confirmed in writing with a cell phone text message to highlight the purpose of the interview. The semi-structured questionnaire was sent as an attachment with the cell phone text message and this approach aided the interviewees to prepare adequately for the interview in advance. Each interview was phone-recorded and subsequently transcribed. The transcribed data was analysed using content and comparative analysis.

FINDINGS AND DISCUSSIONS

Profile of respondents

Table 1 depicts the occupations of the respondents who were interviewed; where Respondent A and Respondent B were construction managers, and Respondents C and Respondent D were

Safety Officers. With respect to occupation, it is evident from Table 1 that 50% (2) of respondents were construction managers and 50% (2) was safety officers, and this suggests both positions participated in the study and were equally represented.

Table 1: Profiles of respondents

Project /Respo nndent	Position	Gender	Qualification	Experience	Duration	Location	Means for recording
A	Construction manager	Male	BTech	4 years	30min	Remote	Telephone interview
B	Construction manager	Male	B(Hnrs)	3 years	30min	Site office	Notes
C	Health and safety officer	Female	ND	5 years	30min	Officer's Office	Notes
D	Health and safety officer	Male	ND	2 years	45min	Officer's office	Notes

Findings and discussions on measures in place for effective implementation of environmental sustainability in construction projects

Perspectives of construction managers

Construction managers were interviewed to indicate measures in place for effective implementation of environmental sustainability. Respondent A indicated that there was an environmental assessment plan in place. Respondent A further indicated environmental assessment plan helps to identify and obtain any relevant information in relation to the impact that the construction project may cause on the environment. Environment assessment plan includes identifying sensitive environmental areas (that are regarded as "no go areas) or users that may be affected by construction activities, where residents to adjacent site could either be affected by excessive noise and pollution from construction activities or may experience the reduced value of amenity. Respondent A further highlighted the effectiveness of the environmental assessment plan and how it is carried out. Respondent A strongly believed the assessment efficiently monitors baseline air, water quality and noise levels close to the construction site. Expected noise levels from construction activities which may affect the adjoining community is assessed. The respondent added that a desk study is undertaken to ascertain potentially contaminated sites in and around the construction area and conduct a soil investigation to ascertain soils that are suspected of being contaminated before construction activities begins.

Respondent A revealed that during construction activities, a lot of materials are being used, and all sorts of possible air pollutants arise. The respondent was asked in what ways air pollution risks are mitigated. The respondent indicated that they make use of water because it has low cost implications and gives excellent results. Respondent A further mentioned that they apply water on the site at least two days or more, depending on the atmospheric conditions while managing the quantity of water applied to prevent excess water that can cause erosion problems. The respondent indicated that water tanker is driven on site spraying water over the

affected areas, to prevent dust. The respondent indicated that the earthwork trade such as bulk excavations are potential source of dust on their site, therefore they ensure that works associated with this trade are tactically executed in order to minimise dust disturbance as much as possible. During dry weather conditions, all dusty activities are damped down and earthworks are covered. In cases where cutting and grinding requires to be done on site, they follow a technique to reduce dust emissions. If materials, such as bricks or concrete slabs, are cut with a power tool without suppression or extraction, a second worker pours water from a plastic bottle over the material as it is being cut. The respondent strongly believes that this reduces the amount of dust generated. When dealing with waste disposal, the respondents indicated that they have good practices they follow on site and which is mainly to do with buying and storing the materials on site. To reduce the amount of waste, the respondents stipulated that they ensure that they order the amount of materials needed as accurately as possible and arrange for 'just in time' deliveries to reduce storage and material losses. The respondent further elaborated that they ensure that storage areas are safe, secure and weatherproof (where required).

The respondent further indicated that liquids are stored away from drains, burns and in banded areas to prevent pollution and keep the site tidy to reduce material losses and waste. Concerning the issue of noise pollution, the respondent indicated that they use what is referred to as ''sequencing and scheduling'' of construction operations. The respondent inferred that noise pollution falls under one of the biggest problems are faced in the project mainly because it is adjacent to residential properties. In mitigating the noise levels on site, several noisy operations are scheduled concurrently to take advantage of the fact that the combined noise levels produced may not be significantly greater than the level produced if the operations were performed separately.

The construction manager in Project B was asked about measures put in place to ensure that during construction, the well-being of the environment is not compromised. The respondent indicated that feasibility study, quality control regarding dust and noise pollution and management of natural resources including soil material and plantation is carried out before the commencement of the project. In relation to how air pollution is mitigated on site, the respondent indicated that they have dust control measures which include watering the entire site's access roads as well as maintenance of temporary roads. The respondent added that according to observations, unpaved temporarily access roads can account for a significant proportion of dust emissions, particularly during dry or windy conditions, when the generation of dust through the movement of vehicles is exacerbated therefore unpaved temporarily access roads are damped down both within and outside the site.

When dealing with waste disposal on site, the respondent specified that they have provided skippers where all waste materials will be deposited that excavated material is used to close off all holes and excavated areas. To reduce noise levels, the respondent stated that site plants are regularly maintained because as they get old and they have tendencies of making bigger sound. The respondent further added that they also provide access roads which are far from people and houses provide good and quality plant and educate local communities, including their employees with regard to how to prevent noise pollution which may include noise reducing agencies. The respondent also highlighted the importance of mitigating noise levels on site

especially for the sake of the health of employees and provision and usage of ear plugs during construction is ensured.

Perspectives of safety officers

The health and safety officer referred to as Respondent C indicated that they have an environmental management plan in place to ensure that the environmental well-being is not compromised during construction. The plan includes spillage, waste, resources, management and how to address different types of levels and exposure in relation to environmental management. The respondent further elaborated on the plan that helps to reduce the adverse impact of construction activities on the environment. The respondent indicated that the plan is regularly updated to meet new risks or where inspections, monitoring or audit reveal that measures are ineffective as well as to achieve ongoing improvement.

To reduce air pollution, the health and safety officer stipulated that they conduct a survey relating to the scope of work. When there is a lot of dust generated, a dust monitoring survey is put in place and it works as a control measure, suppressing the dust with water application. Another interview question was how the site deals with waste disposal. The respondent indicated that between types of waste is differentiated and categorised as either hazardous or general waste. The waste is stored in different marked skippers and disposed at an approved and certified waste disposal company. To mitigate noise levels, the respondent indicated that they use alternative ways of construction from the traditional one such as use of vibration or hydraulic insertion techniques as an alternative to driving pile. The responded identified drilling holes for casting in place piles is another alternative that produces noise levels significantly lower than the traditional driving method. The respondent further added that compressors are significantly quieter, hence they opted diesel or gasoline engine powered compressors.

Further, Respondent D who was also a health and safety officer was interviewed. To ensure that the environmental well-being is not compromised, Respondent D indicated the importance of having an execution plan in place. The respondent further elaborated that a well-defined scope of work is put in place, potential environmental threats that exist and mitigation actions to be put in place are identified to ensure that the environment is not compromised. According to the respondent, the risks that could impact the environment due to this project are air and noise pollution coupled with interference with the environment where the natural habitat is threatened by manmade actions. The respondent indicated that the first thing before any project commences on site is that, the scope of work must be clearly defined, and then indicate the extent of pollution that will generated in the course of executing the work. To deal with waste management on site, the respondent clearly stated that there is a formal waste disposal plan put in place and after disposing a waste disposal certificate is obtained. The respondent further elaborated that there are specific areas where waste is disposed. It is a legitimate area where after disposing a certificate indicating the amount of oil disposed is issued and when authorities come on site to check they will find proof of quantities of waste disposed.

When asked how nose is controlled on site, the respondent indicated that one of the effective noise mitigation technique is to state clearly what the nature of the job is stay within your

boundaries, another way to mitigate noise is by using equipment which allows for minimal noise.

CONCLUSIONS

Both construction managers and safety officers have expressed their opinions with regard to the different ways in which their firms deal with issues pertaining to environmental sustainability in construction projects. The following conclusions can be drawn based on the findings. The construction managers, as part of the project management team highlighted that environmentally sustainable measures put in place before construction commences includes the environmental assessment plan which helps to identify and obtain information concerning any relevant environmental impact that the construction project may cause a feasibility study of the site and the surrounding, a proper execution plan and environmental assessment plan. Whereas the safety officers indicated that they have an environmental management plan as part of their safety program as well as a defined scope of work in place to ensure that the environmental well-being is not compromised. They further stipulated that during construction a formal waste disposal plan is put in place, which also serves to ensure a clean and safer environment for the workers. This is one of their duties as safety officers. Waste disposal management techniques used by construction managers included waste plan and making sure that waste must be stored in different marked skippers and be disposed at an approved and certified waste disposal company.

The effective noise mitigation techniques adapted by construction managers is to state clearly the nature of the job and stay within boundaries. The safety officers highlighted that the use of equipment which allows for minimal noise level, use of alternative ways of construction from the traditional one, for example, alternative to driving piles, constructing shields around stationary noise generating equipment and sequencing and scheduling' of construction operations are also measures that are used on site to mitigate noise levels.

With regard to air pollution reduction measures, both the construction managers and safety officers concurred that one of the measures they have in place which is conducting a survey relating to the scope of work, getting information on the measure and amount of dust that will be generated and coming up with ways to mitigate or reduce it. The dust control measures identified by construction managers included watering all the access roads on site, as well as maintenance of temporary roads.

Even though the respondents had different views, it is evident that this is based on the different duties on site. Taubit (2010) concurs that construction managers and safety have the same goal which is conserving resources both human and environmental. A discussion of sustainability brings attention to safety.

RECOMMENDATIONS

Based on the perceptions of construction managers and safety officers, it is recommended that there should be a broader study in analysing and assessing the different views of both personnel regarding measure of effective implementation of environmental sustainability. The different

perceptions should be compiled and evaluated thereafter establishing a solid standard assessment plan that regulates measures ensuring effective implementation of environmental sustainability. Moreover, a law regarding these measures implemented and regulated to ensure they are adhered to by construction firms during construction to ensure a sustainable future.

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A PILOT STUDY TO DETERMINE THE INFLUENCE OF STRATEGIC MANAGEMENT PRACTICES IN INFLUENCING SUSTAINABILITY DECISIONS IN THE CONSTRUCTION INDUSTRY

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Key Words: Construction, Sustainable, Strategic Management, Organisation.

Abstract:

The Construction Industry is a resource based industry which utilises labor and resources which are used to create competitive advantage thereby allowing for the development of sustainability in a construction organisation. The importance of Strategic Management of these resources has gained a significant importance in Construction Organizations as they seek to become sustainable. Strategic Management decisions on the positioning, direction and focus of a company can all have major impacts on the general strategic development of work practices within an organization in developing sustainability, such as the use of new technologies and managing both tangible and intangible resources effectively. This aim of this research project was to investigate the extent to which strategic management practices influence the sustainability directions of construction industry organization. Structured interviews with senior construction professionals were used to collect qualitative data. The key finding from the study participants agreed that maintaining a competitive advantage was the key to creating sustainability in an organization. In addition strategic management in its wider context was seen as key driver or important consideration in attaining sustainability. The scoping study provides a useful platform for further investigations on the strategic management as a driver in influencing sustainable decision making in the construction industry.

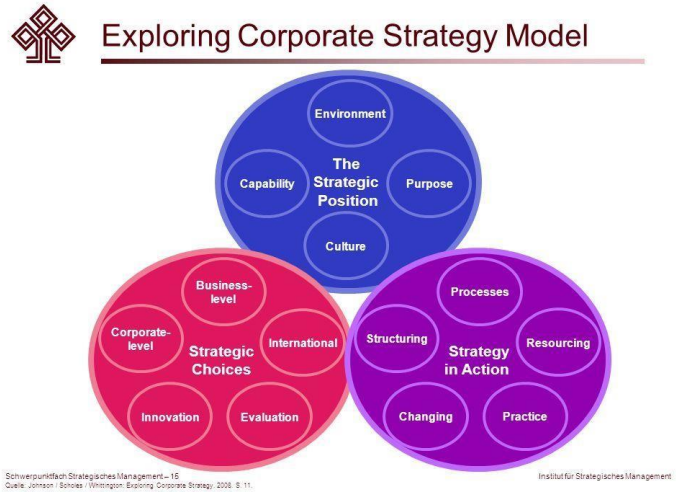
INTRODUCTION

In all organisations building sustainability is one of the key components for any business to develop, remain relevant and survive. There are many ways to build sustainability in construction organisations such as the development and use of new technologies, using the latest in new construction processes and materials, and managing both tangible and intangible resources effectively. With the Construction Industry very much being a labour and resource based industry, how these assets are developed, managed, and utilised to build sustainability in a construction organisation can have a huge bearing on the sustainability of that organisation. Clearly at this point it is important to define what a "**sustainable organisation"** in the context of the construction industry is and in this regard if we look at the United Nations definition of sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (United Nations General Assembly, 1987, p. 43).

On further examination into research conducted looking at the overall terminology of what constitutes a **"sustainable organisation"** by definition, it is clear that there is no one overarching all-encompassing definition which delivers a sustainable organization as a whole in the construction industry. The research highlights specific elements such as environmental, human resources, and technology and highlights terminology such as sustainable development along with other inputs which all contribute to varying degrees in part to the creation of a sustainable organization.

Strategic Managers manage by developing a strategy for the organisation on how it will achieve its goals and objectives. This is defined as "Strategic Management" and has been defined by Johnson Et al, 2008, Exploring Corporate Strategy p 12 *as*

> *"having three main elements within it, as understanding the strategic position of an organisation, making strategic choices for the future and managing strategy in action, with various processes within each element contributing to the overall ability to manage in a strategic manner"* *(Johnson et 2008. P12)*



Sustainability can be achieved by the incorporation of Strategic Management decisions to use sustainable practices which will influence the sustainability of the organization. If we look to context of sustainable organisations within a construction setting from research, it is clear that the sustainable practices that an organisation adopts define its status as being a sustainable organisation.

With the area of sustainable construction organisations being such a broad area, and with the use of strategic management used as a way of achieving sustainability, it is important to conduct a study reviewing the research literature to identify the key concepts of the area of strategic management within the context of achieving sustainability within the construction industry. This will allow for any gaps in literature to be identified where no research has taken place

before in relation to strategic management practices in delivering sustainable organisations within the construction industry. This will be done by way of a scoping study.

This scoping study will be conducted using the methodological five stage framework as developed by Arksey and O Malley's 2005 which allows for a step by step process which should highlight any gaps in research in this area. As defined by Arksey and O Malley in their 2005 research
Scoping studies are

> *"Commonly undertaken to examine the extent, range, and nature of research activity in a topic area; determine the value and potential scope and cost of undertaking a full systematic review; summarize and disseminate research findings; and identify research gaps in the existing literature"*
> *(Arksey and O'Malley, 2005)*

RESEARCH METHODOLOGY

Arksey and O'Malley were the first to publish a methodological framework for conducting scoping reviews. They proposed an iterative six-stage process: (1) identifying the research question, (2) Identifying relevant studies, (3) study selection, (4) charting the data, (5) collating, summarizing and reporting the results, and (6) an optional consultation exercise (Arksey and O'Malley, **2005**). For the purpose of this scoping study it is the intention to use the first five stages of Arksey and O Malley's framework as there will be no requirement for a consultation exercise.

Identifying the research question

In seeking to review the role of Strategic Management in Building Sustainable Organisations in the construction industry the starting point has to be the identification of the research question. At this time a broad search scope encompassing all aspects of strategic management and organisation/sustainable construction will be considered in search terms.

Identifying Relevant Studies.

It was decided to use two main electronic databases as the search engines for the Scoping study review. "***Discover"*** which is accessed through the Leeds Beckett Online library portal and ***"Google Scholar***" which is accessed through the Google online search engine. Key search terms were developed from the research question to allow for a more focused search relevant to the two main areas of the research question, that being Strategic Management and Sustainable Organisations in the Construction Industry.

Table 1: Key search terms

1	(Strategic Management) **AND (**The Construction Industry)
2	(Strategic Management) **AND** (Sustainable Organisations)
3	(Strategic Management) **AND** (Building Sustainable Organisations in the Construction Industry)
4	(Strategic Management) **AND** (Building Sustainable Organisations

Study selection

It was decided at the outset to tailor the scoping study to specific criteria which would allow for the research material being searched to be relevant in terms of *Geography, Time period, Language, Article Type, and Relevance.* An initial search using ***"Discover"*** using the term (Strategic Management) **AND (**The Construction Industry) generated 492,951 results and this further reinforced the point that a need for a selection criteria was needed. This resulted in an inclusion and exclusion criteria being developed as shown in Table 2 below. It was decided to use a time frame from 1980 onwards so as to allow for all articles relating to the research question as strategic management gained real relevance in business around this time and was wrote extensively on in the Harvard Business Review of July 1980 with the Article Strategic Management for Competitive Advantage Gluck et al, HBR, 1980, Online.

Table 2: Inclusion and Exclusion Criteria.

Criteria	Inclusion	Exclusion
Time Period	1980 -2017	Articles prior to 1980
Language	English	No Foreign Language studies
Geographic Focus	Great Britain/USA	All other studies from other countries
Article Type	Peer reviewed Scholarly Journals/Doctoral research	Non Academic Articles will not be considered
Relevance	Articles that focus on Strat Management and Building Sustainable Construction Organisation	Literature which only makes a brief reference to the research topic.

With the above inclusion and exclusion criteria now developed the work of researching the literature began. This involved an initial search using the above criteria in which using the (*Strategic Management*) **AND (***The Construction Industry*) still produced 10,664 results from the USA and 4,417 from the UK.

At this point a second stage inclusion process was needed and the need to be more specific was evident and the search term now was to include the following (*Strategic Management*) **AND** (*Building Sustainable Organisations in the Construction Industry*). This narrowed down the scale of literature significantly and produced 716 results for Great Britain and 285 results for the USA.

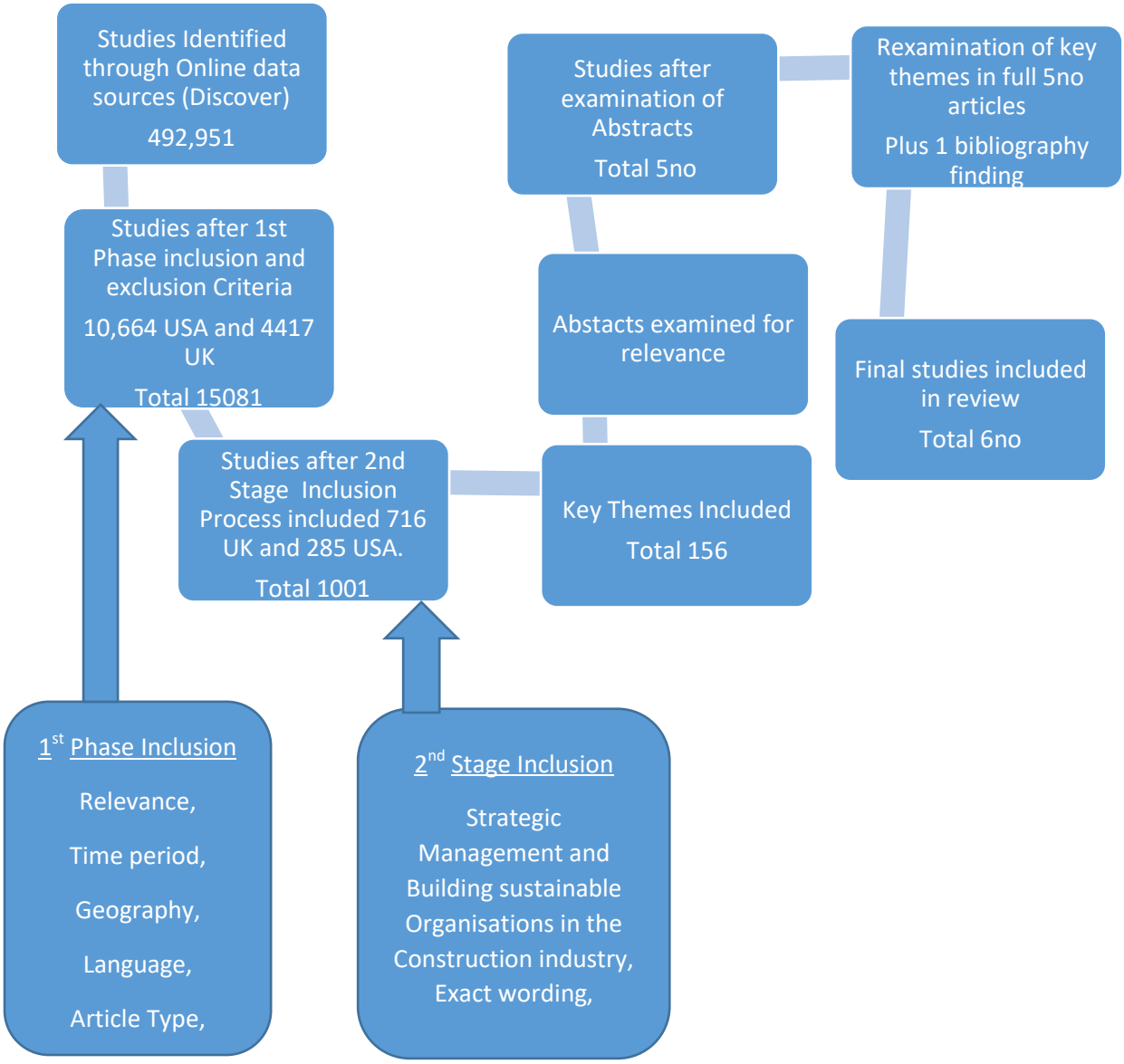
With further criteria focusing on key themes of *Sustainable Development, United Kingdom, Economic Development, Management, Business Planning, Construction Industry and Sustainability,* the literature being reviewed was then reduced down to 156no articles relating to the geographic location of Great Britain. A further 4 no articles were included from a similar search in the USA and none of these were deemed to be worthy of inclusion in the final list of research papers due to them lacking the relevant content in relation to the key themes based on the research question.

Therefore a literature review of the abstracts of these 156 no articles was conducted and the relevance of these abstracts in light of the research question posed eliminated further some duplicated studies and studies deemed not relevant to the research being reviewed. Familiarity with the research question allowed for the researcher to make an informed judgement on the relevance of these abstracts and whether they warranted inclusion in the final list of research papers. This resulted in a final list of 5no studies which were deemed suitable for a full literature review in the context of the research question posed. This process is fully detailed as the *Scoping review process* and is detailed in graphic form in Table 3 below.

Charting the Data Collection

This involved the charting of key elements of information within the data being reviewed in a manner which would allow for easy interpretation of the data reviewed. This was done by way of constructing a chart displaying the information in a structured manner. It involved analysing and sorting the data relevant to key themes. These themes related to areas of relevance in terms of the Author, Year of publication, population type, theoretical framework, strength of study, weakness of study, recommendations of the study, see table 4 for a visual interpretation of the chart.

The scoping review process: Table 3



(5) Collating, Summarising and reporting the results

Table 4 Scoping study review table

Study No Author	Methodology	Data Collection Technique	Theoretical Framework	Population Type	Strengths	Limitations
					Focused review	Potential researcher Bias
(1) Green et al (2008)	Qualitative	Interpretative Review	No	No respondents	Strong study depth Structured research	Lack of validation of findings Secondary research data only
(2) Dolphin, (2004)	Qualitative	Unstructured interview	No	Spokeman of Company	Strong study depth Complimentary approach Validation of findings interviews	Unstructured Time consuming Not data specific
(3) Brennan, Cotgrave (2014)	Qualitative	Semi Structured Interview	Yes	Focus Groups	Diverse and complimentary Validation of findings Addition of Framework	Unstructured Time consum Not data specific
(4) Davey Et al (2002)	Qualitative	Mixed method Observation+ Report of discussions	Yes	6 Staff members	Focused methodology Strong Study Depth Structured validation of Findings Addition of framework	Very Time consuming Difficult to manage Process Full Organisation Commitment
(5) Elias, Scarbrough (2004)	Qualitative	Semi Structured Interview	No	11 Organisations	Focused methodology Structured validation of Findings	Time consuming Board study topic

Adapted from Unuigbe,M Zulu,S.snd Johnstone,D (2017) Understanding the factors contributing to the adoption of sustainability in Sub-Sahara Africa- A Scoping Study Review

Study **1** with its interpretive critique type approach to review existing literature is the study which is most aligned to the research question being posed. It identifies the importance of the works of the leading business management strategists and acknowledges the writings of academics in the field of strategic management such as Michael Porter from Harvard. It focuses its research on creating competitive advantage as being a key driver in the delivery of sustainable organisations. It notes that Strategic decisions need to be conceptualized and of key

importance would be the need to shift from a 'being ontology to a becoming ontology' (cf.Chia, 1995) cited in Green et al (2008). It is the contention of the author that this research paper has touched on various elements of the research question posed but again its focus is very much on "the now" and has failed to pick up on the importance of these strategic decisions in the context of creating sustainability for an organisation.

Study **2** using its qualitative mono methodology with unstructured interviews, sought to interpret responses relating to the questions of the importance of creating a good corporate reputation as being a key driver for an organisation in delivering competitive advantage. It identifies the need for sustaining a favourable corporate reputation to create corporate competitive advantage (Gotsoi and Wilson, 2001b) as cited in Dolphin, R (2004). This paper now brings the issue of sustainability in the context of organisation reputation to the fore but fails to acknowledge the role that strategic management decisions as a collective can deliver in creating organisational sustainability.

Study **3** using a focus group method to collect data sought to differentiate its approach to data collection from previous studies in this field by using a qualitative approach and it used the framework model adopted from Srivastava and Thomson (2009) as cited in Brennan et al (2014) to assist in this methodology. It comments that previous studies in the area have tended to use quantitative data analysis. It further comments that using qualitative data provides a more indepth view as to why the status quo remains with regards to sustainable development and the construction industry. Study 3 paper seeks to gain insight as to how adoption of more sustainable methods and practices can help influence sustainability in the construction sector. In this regard it is aligned with the research question being sought in this scoping exercise. It findings were interesting in that the participants in this study found that too achieve change to deliver sustainability in the construction industry required 12 subthemes, being, Legislation, Evidence, Initiatives, Requirement, Incentives, Education/Awareness, Continuous Professional Development, Collaboration, Economy, Early Involvement. Brennan, Cotgrave, (2014). None of the focus groups or any of the interpretive data referred to the major role that strategic management can play in the development of sustainability which was a very surprising omission from this research.

Study **4** used a methodology with action learning being at its core. It involved 6 middle ranking managers meeting for 3 to 4 hours per month over a 12-month period and this grouping became known as the SET. Data was collected by way of notes of the discussions at the SET meetings and observations of body language and nonverbal communication between the members noted. Davey, et al (2002). The Set Developed over each meeting and resulted in a framework being the 6 stages of set development as highlighted in the research paper. Findings within this paper have indicated that this framework did facilitate a platform for issues to be discussed at a middle ranking level which were then deemed to be of strategic relevance to the company and subsequently reported to senior management for consideration. It is of interest to note that nowhere within the research paper has any reference or causal link been referred to in the context of delivering sustainability which is surprising as it is clearly evident from reading the document that these actions developed from the SET meetings will have some relevance to sustainability.

Study **5** again used a qualitative methodology but this study was conducted using a semi structured interview of 20 Human resources managers. With the title of evaluating Human Capital; an exploratory study of management practice it was interesting to note that this study while focusing on management practice and the role and relevance that the HR department plays in managing human capital, the research has acknowledged the link identified by Sisson and Scullon (1985:36) cited in Elias, Scarbrough (2004) between the scope of HR activities and workforce skills as a 'strategic consistency' and identified certain firms in engineering of using a strategic approach to HR, however they were using strategic decision making as a means to manage staff and evaluate staff, as opposed to using strategic decision making in the wider context of the organisation as the primary driver in the delivery of a sustainable organisation. The respondents failed to see the wider context of strategic management in delivering sustainability.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the research papers **1-5** used in the scoping study, while being relevant to the research question posed in this study in the context of addressing issues pertaining to delivering sustainability within the construction industry, have left important gaps in the research as noted in each section above. In particular, the researchers have focused on individualised factors influencing sustainability such as creating competitive advantage, managing human capital, and enhancing the corporate reputation as all have a relevance to sustainability. However, the researchers have fallen short by not identifying the overall value of the role that strategic management plays in delivering all of these processes as a collective, in the formation of an allencompassing strategy of sustainability in seeking to deliver a sustainable construction organisation. This has left a research gap in this area in identifying the best way that this can be achieved and how best to develop a model framework which would assist with the implementation of a strategic management based sustainability model. It is suggested that a qualitative methodology most likely would be the best way to advance this research as this has proven to be relatively successful in the studies used in this research to extrapolate opinion from participants to the research questions posed. It will allow for the development of a framework based on the key findings which would be interpreted from the research findings.

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GOOD MANAGEMENT OF CHANGE IS A SINE QUA NON

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Keywords: Change communications, change management, staff empowerment and involvement.

Abstract

In the last 50 years, the number of medical schools in the world has increased, with a growth of 190%. There are currently 22 accredited medical schools in Australia. The University of Sydney is one of the Asia Pacific region's most highly rated education and research institutions, [specific detail], and the university's medical degree (MD) program offers unparalleled opportunities. However, in order remain one the most sought after medical degrees in the country, the MD curriculum needed an update to reflect the current needs of the community. The goal of the redevelopment of the curriculum is that by 2020, the University of Sydney MD Program will deliver a curriculum based on sound educational principles that will recognise and maintain the existing strengths of the program and produce and equip graduates with the qualities to deliver, lead and advocate for culturally competent, research-informed, evidence-based and patientcentred care in Australia and worldwide. In order to make the proposed changes possible, there is a need to have a buy-in from all relevant stakeholders. This paper focuses on the University of Sydney's MD curriculum redevelopment project and examines the approach management bodies took to involve and empower both academic and professional staff in the project. It also explains how the changes were communicated to all stakeholders.

INTRODUCTION

"Tell me, I'll forget; show me, I'll remember; involve me, I'll understand."

The proverb quoted above nicely summarises what this research aims to highlight. This paper studies organisational change management in a curriculum change project at an Australian higher education institution and, more specifically, focuses on analysing the human factors in this process: empowerment, involvement and communication. The connection between environmental changes and organisational changes is one of the main themes in strategic management studies (Østergren & Stensaker, 2009; Perrott, 2009) and institutionalist studies (DiMaggio & Powell, 1983).

There has been a large increase in the number of medical schools around the world. Duvivier et al. (2014) state that over a 47-year period the number of medical schools increased from 566 to 1,642, a growth of 190%. According to the Australian Medical Council (AMC), there are currently 22 accredited medical schools in Australia. This means that the University of Sydney medical degree (MD) program faces a lot of competition and, in order to stay above the competition, the Sydney MD program must be constantly reviewed, updated and

innovated reviewed, updated and innovated. Doing this means that not only will the university attract the best and brightest medical students, but also that the students of this program will graduate as compassionate, diverse and innovative lifelong learners who work in partnership with individuals and communities to improve health through clinical care, education and research.

Thus, making changes to the existing curriculum is expected and needed. The nature of change and change management are often complex. Change is not a new phenomenon; rather, it is an ever-present feature of organisational life, both at an operational and strategic level (Burnes, 2004; Balogun & Hope Hailey, 2004; Carnall, 2003; Kotter, 1996; Luecke, 2003; Moran & Brightman, 2001; Okumus & Hemmington, 1998; Paton & McCalman, 2000; Senior, 2002). Moran and Brightman (2001:111) define change management as "the process of continually renewing an organization's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers."

The goal of the MD curriculum review project at the University of Sydney is to create an innovative, modern and up-to-date medical curriculum so that the program remains competitive and meets the needs of the community. It was recognised early that if the staff were not on board with the proposed changes, it would be hard if not impossible to successfully implement the new curriculum. In order to gain buy-in from staff and all other relevant stakeholders, the project team worked hard at involving stakeholders and empowering them to provide feedback and contribute to the development, innovation, logistics and delivery of the new MD curriculum. The project team aimed to communicate all project updates on a regular basis using a number of methods of communication including email, meetings, staff newsletters, workshops, social media and Town Hall meetings.

BACKGROUND

Ironically, people "both fear and seek change" (Senge, 1990). It is of vital importance to organisations that people are able to undergo continuous change (Rieley & Clarkson, 2001; Burnes, 2004). In the change management literature, researchers have identified change success factors and factors that cause resilience to change (Kotter & Schlesinger, 2008; Verhulst Hatemi & Eaves, 2012). Verhulst et al. (2012) conducted a literature review and identified more than 60 different factors that influence change. The majority of the identified factors are related to people. Some researchers refer to those people factors as "intangibles," the "soft side" and/or the "human factors" of change (Adams, 2003; Verhulst et al., 2012; Boks, 2006; IBM, 2008). According research conducted by Struckman and Yammarino (2003), these "soft side" factors are the hardest to change. This research is supported by an IBM study (2008), which came to the same conclusion.

However, those change researchers also identified some human factors that are indicated as success factors in change management (Verhulst et al., 2012): empowerment, involvement and communication. Several scholars (Adams, 2003; Kegan & Lahey, 2001; Lewis et al., 2006; Karakoc, 2009; Verhulst et al., 2012) concur that empowerment, the

involvement of employees, human commitment to what needs to get implemented, inductive learning, the adaptation of the organisational culture and clear communication are the success factors that will ensure stakeholder commitment and will make the proposed change feasible (IBM, 2008).

Research conducted by Kotter (1995) states that the more that people get involved in the change process, the better the outcome of the change will be, under the condition that the actions performed by the people fit within the broad parameters of the overall vision on the change. Hiatt and Creasey (2003) confirm the importance of engagement, especially within the change team.

Many scholars and practitioners directly link failures of the change process with resistance to change (e.g., Kotter & Schlesinger, 2008; Smith, 2005; Pardo del Val & Martinez Fuentez, 2003). Every change effort will have resistance and the challenge during implementation is to overcome resistance, because whenever there is change, there is also some force pushing in the opposite direction (Belliveau et al., 2004). Resistance as a phenomenon is considered as the most important obstacle in organisational change management, whereby it forms a key element of the study of organisational change. Lewin (1951) notes the impact of resistance to change and emphasised the need for deeper insights in these restraining forces. Schein (1988, 2004, p. 243) describes resistance as "*the enemy of change, the foe which must be overcome if a change effort is to be successful*."

People are particularly likely to resist change when they see it as threatening their jobs and/or interests. This is in line with research conducted by Dunphy et al. (2007), who advocate the need for sufficient organisational and individual training and learning (up-skilling). This indicates that in addition to educating people on the changes and getting them involved, they also need to be up-skilled in order for the staff to embrace the proposed change. Many factors of resistance have been described in the field of organisational change management. Those factors include feeling anxious about the unfamiliar and unknown, feeling inadequate in skills and knowledge, especially if a new procedure way of doing things is interceded and believing that the change will lead to job loss (Dent & Goldberg, 1999; Johansson, 2002; Kotter & Schlesinger, 2008).

However, resistance can be a source of information that can be used to support the change process (Waddell & Sohal, 1998). Cunha et al. (2013) reframe resistance to change and use it as a starting point for improvisation in the change process. Appreciating why and how resistance to change occurs and developing the ability to respond effectively to manifestations of resistance to change is crucial to the success or failure of efforts to achieve organisational change (Smith, 2005).

METHODOLOGY

There is widespread conviction that case studies are useful when studying change (Johnson-Cramer, Cross & Yan, 2003; Muratbekova-Touron, 2005; Van de Ven & Poole, 2005). Case studies are a popular research method used in many studies in disciplines such as sociology

and business for analysing both individuals and groups (Yin, 2009). This type of research has been used to better understand the complex social phenomena. Case studies allow researchers to "retain the holistic and meaningful characteristic of real-life events" (Yin, 2009:4), such as group behaviour and organisational and managerial processes. According to scholars, a case study can utilise the best of both quantitative and qualitative methods (Stoecker, 1991; Stake, 1995; Yin, 2009). Stoecker (1991) suggests that case studies permit researchers to explore different outcomes of wide-ranging processes suggested by theories depending on the different circumstances.

This paper focuses on one case study, which examines the University of Sydney's MD curriculum review. As stated earlier, it can be difficult to understand whether an institution is ready to accept change. To determine the readiness of the University of Sydney's MD program for change, the project management team ran a change sizing survey in order to identify the requirements for change as well as to define the approaches for the required change and to set goals and strategies to achieve the necessary changes. This type of change sizing survey has been successful used at the Universities of British Columbia, Toronto and Washington to assist them with their medical school curriculum renewal initiatives (AMBiT Consulting Inc., 2017). The change sizing was specifically designed to meet the needs of the University of Sydney and it was run in December 2016 for the academic group and in March 2017 for the professional staff group.

The change sizing and readiness survey the fists author developed was based on the ADKAR (awareness, desire, knowledge, ability and reinforcement) model. This change sizing survey can be useful to help leadership and stakeholders understand the magnitude of change. It also helped the project management team to identify what was necessary to ensure the change was accepted, embraced and, later, implemented. The ADKAR model works by assessing individuals and organisations on each of five building blocks in consecutive order for readiness to deliver successful change. By rating each phase of change "element" with a score between "1" (the lowest) and "5" (the highest), an ADKAR "profile" is created. The first element to score three or less is defined as a "barrier point."

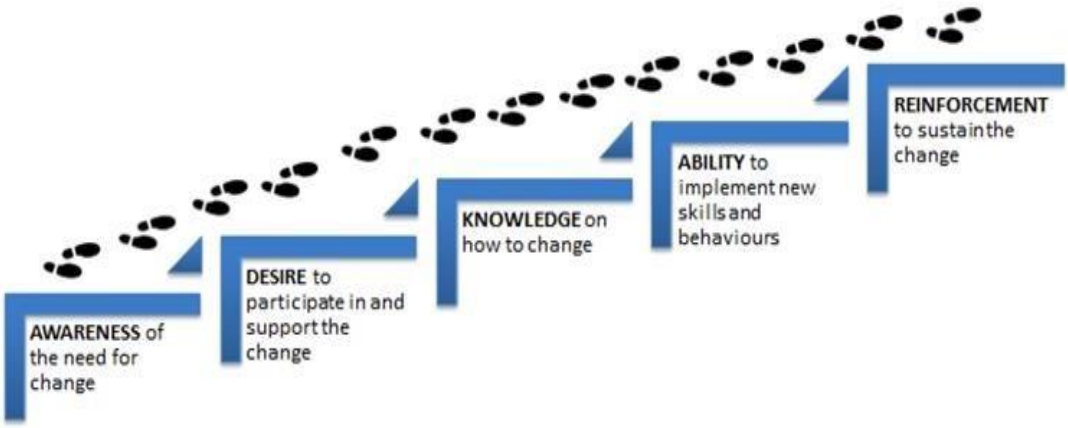


Figure 1: Key processes and five building blocks of ADKAR model (Lad, 2014)

The survey questions were designed and collected online via LimeSurvey. LimeSurvey is a web server-based software that enables users to develop and publish on-line surveys, collect responses, create statistics, and export the resulting data to other applications using a web interface.

The survey participants were asked 17 multiple-choice questions and three open-ended questions. For the multiple-choice questions, participants were given a five-item Likert scale spectrum (strongly disagree; disagree; neither agree nor disagree; agree or strongly agree) spectrum to choose from.

The reason the two groups of staff were asked to take part in the survey is because there was a belief that the two groups of staff were likely to have different concerns and needs. It was thought that as the professional staff are the ones who run the MD program, their perspective of what is needed and their concerns would be different to the academic and senior staff. Additionally, as a significant number of senior staff are part of the MD program's committees and working parties, the researchers consulted and communicated with them closely. It therefore made the most sense to ask the academic and senior staff to complete the survey first in December 2016. The researcher's contacted 52 senior academic staff (i.e. heads of schools, block chairs and professors) via email, and amongst them 34 (65%) participants completed the change sizing survey.

The professional staff were consulted via clinical school visits, presentations, meetings with individual teams, a staff newsletter and Yammer and were asked to take part in the survey in March 2017. 85 professional and clinical school staff were contacted and 44 (45%) participants completed the survey.

RESULTS

In general, the change sizing and readiness survey was well received. Staff conveyed to us that this was the first time during a change project that anyone had taken the time to consult with all staff and get them involved. The survey participants reported that they felt like they had a say in what changes are made to the MD program and that they felt they had gained a better undersetting of how the proposed changes may impact their team and/or themselves after taking part in the survey. The results of the survey are shown in Table 1.

Table 1 Academic and professional staff change sizing results summary

Change sizing results for senior and academic staff	Change sizing results for professional staff
85% of the survey participants stated that there is a need for the curriculum to be reviewed and updated	Just over 70% of the survey participants stated that there is a need for the renewal of the current MD curriculum
97% of the participants understand that the new MD curriculum renewal project is a large-scale, complex project	91% of the participants understand that the new MD curriculum renewal project is a large-scale, complex project

All participants (100%) stated that there is a need for additional resources to ensure the new MD curriculum renewal project is a success	89% of the participants stated that there is a need for additional resources to ensure the new MD curriculum renewal project is a success
94% of the participants believe that the transition years will be challenging	86% of the participants believe that the transition years will be challenging
94% of the participants said that additional resources and funding will be required during the transition years	86% of the participants said that additional resources and funding will be required during the transition years

This survey was an opportunity for academic, clinical and professional staff to provide us with their opinions and feedback on the MD curriculum renewal project and how they think it will impact them and their team. The results of the survey show that main issues/concerns for this group are:

1. Resourcing (staff and financial resources needed)
2. Need for change
3. Complexity
4. Transition (more support in the transition years as well as taking fewer students in 2019 and 2020)
5. Up-skilling of current staff (providing training and support)

Professional staff also provided their opinions and feedback on the MD curriculum renewal project and how they think it will impact on them and their team. The results of the survey show that main issues/concerns that professional staff identified are:

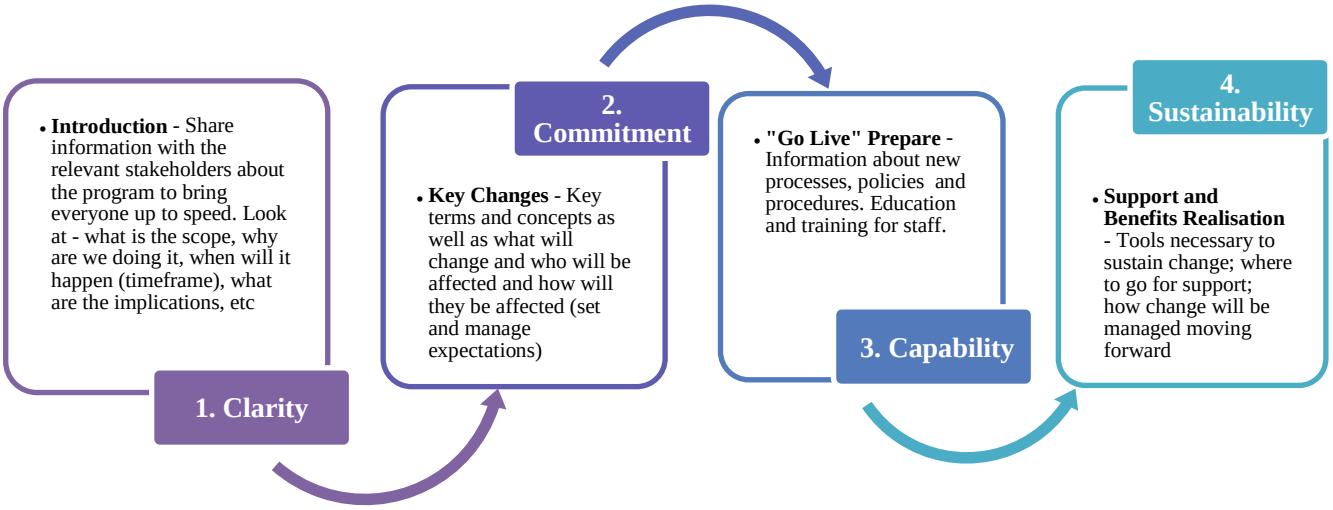
1. Resourcing (staff and financial resources needed)
2. Consultation and communication (regular updates)
3. Challenges around the transition years and logistics of running the programs simultaneously
4. Updating the curriculum after it has been implemented
5. Up-skilling of current staff (providing training and support)

The majority (85%) of all survey participants agree that there is a need for the renewal of the current MD curriculum. This is a great start, as that means that the key people in the change efforts agree that change is needed so they are more likely to support the change efforts.

The new MD curriculum renewal project team needs to ensure effective and efficient change management by setting expectations correctly and successfully managing stakeholder perceptions throughout the project lifecycle. Given human dynamics, it is important to establish awareness and clarity about the project months and even years in

advance of the 'go live' and then to build commitment to the program as 'go live' draws closer.

Figure 2: Communication Processes Used for Preparing Curriculum Change



As shown by the clarity box in Figure 2, a lack of communication, inconsistent messages and the resulting misunderstandings will lead to rumours that demoralise people and to a lack of commitment to change. This is why this project placed high importance on consulting with all relevant stakeholders and why information-sharing is being conducted utilising a vast number of communication channels, as indicated in Table 2.

Table 2: Communication and Engagement Activities in the Change Project

Communication activities	Engagement Activities
Emails	Committees and working parties
Newsletters	Question and answer sessions
Videos	Town hall meetings
Posters and flyers	Learn and lunch sessions
Presentation material (for e.g., PowerPoint slides and posters)	Interviews and focus groups
Internal postings	Informal hallway conversations and unscheduled office drop-bys

Communicating messages is seen important in all phases of this change project. This was done using methods that would foster engagement with the project's stakeholders by engaging them in dynamic interactions. Engaging the stakeholders also meant that they understood and had a say in what the key changes were. This help to identify which staff need to be trained, whose roles would change, who else needs be hired and what technologies are needed to make the proposed changes.

For this project to be feasible, it was necessary for the project management team to work together with all of the stakeholders with open and honest communication. This approach has benefitted this project because the stakeholders were engaged and empowered and

taking part in the project meant that they understood why the change is important and they therefore supported it.

DISCUSSION

The aim of all project communications is to keep everyone on board and supporting the project schedule as the organisation works towards its end goal. The main goal of the change management strategy is to involve all stakeholders in the decision-making process so that they are informed, willing, able and ready to adapt to the new settings.

When changes are communicated to the stakeholders on a regular basis with clear and consistent messages, it will result in broad understanding of the project and the significance of the change and its potential impact to the organisation. It will also lead to buy-in from stakeholders, who will end up supporting the project as well as eliminating the rumours that demoralise people and result in a lack of commitment to change.

There are a number of working parties and committees where stockholders have the opportunities to get involve, express themselves, and feel empowered. Their involvement is of great assistance to the project and it also lead to buy-in from stakeholders.

Overall, this MD curriculum change is not just about updating and reinventing a new MD curriculum: it is also about consulting all relevant stakeholders, getting them involved, giving them a voice and ensuring that the curriculum changes are sustainable in the long run. Involving the stakeholders through open dialogue and communication provided the project with stakeholder buy-in and it meant that proposed changes were received with an open and positive attitude.

CONCLUSION

Change management in higher education institutions is always a challenging task and it becomes more complex when an institution has renowned reputation in the world community and is expected to offer a competitive education. Thus, the University of Sydney's MD curriculum change project has not only made an impactful contribution but a challenging attempt. Analysis of what was needed for successful change implementation, as justified in this case study with a positive response by most of (85%) the stakeholders.

Involving the academic and professional staff in change-related decision-making has been successful and supported by the management bodies. Appropriate communication methods (email, telephone, newsletters, videos, posters and presentations) and processes (clarity, commitment, capability and sustainability) were adopted in this project to make the changes meaningful and effective to all stakeholders. Overall, this MD curriculum redevelopment project can be a sign of good management, particularly in the communication management in the change project in the context of a higher education institution.

The lessons learned and recommendations that this paper will conclude with is that it is of outermost importance to ensure effective and efficient change management by setting expectations correctly and successfully managing stakeholder perceptions throughout the

project lifecycle. Given human dynamics, it is important to establish awareness and clarity about the project months and even years in advance of the 'go live' and then to build commitment to the program as 'go live' draws closer.

The second recommendation is that in order to ensure a sustainable curriculum is to invest in people, for example by up-skilling them, and to involve and empower both academic and professional staff and to get them involved in the curriculum change process.

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PARTICIPANT INFLUENCES ON THE SUCCESS OF CRITICAL PATH METHOD PLANNING IN CONSTRUCTION PROJECT ENVIRONMENTS

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Keywords: critical path method, planning, planner, supply chain, lean construction

Abstract

Critical Path Method planning has been considered as a flawed programming technique even though it remains the planning method preferred by the majority of contractors, clients, and dispute resolution practitioners in the construction industry. Newer methods adopting a social based approach, such as Last Planner® System and Collaborative Planning have, however, not yet managed to position themselves as the method of first choice. A reconsideration of Critical Path Method by critically examining extant literature across construction programme management has identified several approaches to Critical Path Method. These are CPM in logic networks, some work critically reviewing the practitioners of CPM planning, and the modern collaborative planning methodologies. There appears to be a paucity of work on the practical application of CPM at construction contracting environments. This paper reports upon ongoing research to assess the overall adoption and application of Critical Path Method in construction contracting organisations within their project environments. To investigate, exploratory qualitative data was collected through a purposive sample of six semi-structured interviews with construction management personnel. This comprised three Project Managers from one main contractor organisation, a Planner from the same main contractor organisation, and two Planners from separate sub-contractor organisations. Preliminary results indicated Critical Path Method operates within inconsistent and poorly structured environments at contracting organisations and there is little evidence of authoritative implementation and a culture of apathy towards Critical Path Method is observed. An agenda for further work is presented which includes a recommendation for further empirical study focusing on the functional roles, behaviours, and attitudes of people at construction contracting organisations in determining the later success of CPMP planning within their construction project environments.

INTRODUCTION

This paper is part of an ongoing research project to investigate and understand the adoption and application of traditional Critical Path Method (CPM) planning at construction contracting organisations. CPM remains the most commonly used planning technique in construction project environments (Ammar, 2012), possibly due to familiarity, popularity, and specification by construction clients. In construction dispute resolution CPM is commonly used to demonstrate effects of delay, disruption, and time entitlement (Livengood, 2016). Despite widespread use CPM is criticised for its effectiveness as a planning tool (Tommelein, Riley and

Howell, 1999). This paper critically investigates CPM adoption and application within the context of a construction project environment.

Circa 50 percent of UK construction projects are delivered late (Colin and Retik, 1997). On the whole, complex construction projects in the UK are likely to be finished more than six months late (CIOB 2008). Critical Path Method planning generally operates in complex project environments with a prevalence of trade sub-letting, work package fragmentation, adversarial relationships, and sub-contract labour crews. Risk transferral via downstream sub-letting creates dislocated environments not well suited to traditional CPM planning. This study critically investigates CPM within the context of a live construction project environment, with a focus on the participants' influence on its success within that environment.

Note: the terms 'supply chain' and 'sub-contractors' are used interchangeably in this paper.

CONSTRUCTION PROGRAMME MANAGEMENT

Critical Path Method has been traditionally studied in a logical way in most research, which conducted and reported on investigations into the mathematical, computational, and algorithmic characteristics of network analysis (Kelley, 1961; Aquilano and Smith, 1980). Originating as a production network analysis method in industrial, military, and production environments the transposition of CPM into construction environments was "A non-computer approach to the critical path method for construction" (Fondahl, 1961).

The logic schedule was again assessed in "Key determinants for construction schedule performance" by Kog et al (1999), whereas Winch and Kelsey (2005) directly questioned the planner role. Similarly, Laufer and Tucker (1987) had asked whether construction project planning was doing its job? "What is pre-project planning anyway" (Gibson et al, 2006) turned attention towards a lessons-learned study of the pre-construction planning process. The practical application of CPM planning does not appear to be considered in these or similar works.

New lean methodologies (imported from automotive industries) offered alternative approaches to traditional CPM technique (Ballard, 2000; Daniel, Pasquire and Dickens, 2014). Categorised as Collaborative Planning these approaches comprise project systems such as Lean Construction, Last Planner® System. Other variants are Agile Project Management, AgiLean Project Management, Six Sigma, Lean Six Sigma. Their approach is characterised by greater collaboration and inclusivity throughout the project life-cycle, particularly of site work-crews, and are seen as improvements to the technical-rational nature of CPM planning.

The practical application of CPM is not considered in key construction texts: Lester (2006); Pierce (2013). Similar lack of guidance on CPM is in HM Government construction-industry reports: Latham (1994) and Egan (1998) and within best-practice publications: British Standards Institution (2010); Association of Project Management (2012); Chartered Institute of Building (2016).

RESEARCH APPROACH

This research design adopts a qualitative study to allow a process of interpretation of data for the purpose of discovering concepts and relationships (Corbin and Strauss, 2008). The collation of data is by interviews, commonly found in case study research (Yin, 2017). The research position is interpretivist in nature, with the qualitative strategy emphasising social reality research over quantification of data (Bryman, 2015).
The case study was undertaken at a construction project in the UK Midlands area that had entered into its contract phase. The final account is projected to be circa £300M and the main contractor is a large construction organisation who operate predominantly on the UK mainland. In addition, two sub-contract companies engaged on the same project were included in the study. Both subcontract organisations are major supply chain contractors, one operating in the steel erection sector and the other operating in the building services sectors.

Interviewees were selected as a cross-section sample of construction management personnel within the case study organisations. Four construction staff from the main contractor, and one member of staff each from the sub-contractors were interviewed. Each participant was employed full-time as either a project manager or project planner and possessed between fifteen and thirty two years' experience in the construction industry. The mean years of experience of the sample was 26.2.

The questions posed in the interviews were open and exploratory designed to elicit rich data for further analysis. The eleven questions span common topics in project planning and are developed from observations and experience within a practitioner environment. The interviews used a semistructured approach on a personal (face-to-face) basis with the five key topics derived from the literature:

Programme Key Challenges

1. What do you perceive are the main challenges for contractors planning with Critical Path Method?

Programme Development, Co-ordination and Integration

2. How much do attitudes and cultures within a company influence the successful development and coordination of an integrated construction programme?
3. The development of construction programmes require many iterative passes around the supply chain. How well do you feel this process is managed?
4. How do you feel the programme development and co-ordination process could be improved?

Programme Procedures, Methods and Techniques

5. What are the methods, techniques and protocols that construction organisations use to develop, co-ordinate and integrate critical path programmes?
6. Who has the responsibility for undertaking the project planning role at your organisation?
7. What processes do you follow to establish and integrate the various sub-contract trade sections of the construction programme?

Planning Software, Training and Development

8. What programme scheduling software is used at your organisation?

9. What planning and programming training, both formal and informal, is provided to those responsible for undertaking the planning role?

10. How is the planning role nurtured and supported to allow stability, consistency and longevity within the organisation?

Programme Process Framework

11. How do you feel a process similar to the RIBA's Plan of Work would be of use for developing a co-ordinated and integrated programme?

DATA COLLECTION AND ANALYSIS

The data from the six interviews has been transcribed into written text and an open coding analytical process undertaken. NVivo 11 qualitative data analysis computer software package was used to code the transcripts at the sentence level to identify categories and concepts. This analysis was to provide an initial exploratory investigation into the subject matter. Open coding allowed the text to be opened up and expose the thoughts, ideas, and meanings contained therein, to uncover, name, and develop concepts (Corbin and Strauss, 2008). Further analytical procedure, such as generation of theory, is not in the scope of this paper.

RESEARCH RESULTS

Question 1 related to the perceived challenges for contracting organisations planning with Critical Path Method. The emerging key concepts from the open coded categories from the transcript data are: 1) fundamental understanding of programmes, 2) resourcing of programmes (plant, materials, and labour), and 3) stages and trade sections of programme. Table 1 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME KEY CHALLENGES		
1. What do you perceive are the main challenges for contractors planning with Critical Path Method?	Data (Examples)	
	People understanding CPM and buying into it. Understanding CPM usage and outputs. Understanding the critical 'spine' through the CPM programme. Early supply chain involvement so they understand programme aspirations. Supply chain nominating their correct person so they understand it. Communicating the critical 'spine' to the supply chain. Better identification of critical and non-critical activities. Resourcing to suit the master programme constraints. Identifying the correct commissioning period. Preserving the commissioning period [from being compressed by delayed installation].	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Understanding CPM and Benefits Supply Chain Understanding Understanding Critical Items Understanding and Focusing on the Critical Path Plant Resource to Support Programme Programme - Commissioning Integration	Understanding of Programmes Resourcing of Programmes Stages of Programmes

Table 1. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 1

Question 2 related to the effects that attitudes and cultures within companies have on the programme development. The emerging key concepts from the open coded categories from the transcript data are: 1) operational cultures at companies, 2) shared understanding of programme, 3) trust required in programmes, and 4) team attitudes to programme development. Table 2 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME DEVELOPMENT, CO-ORDINATION AND INTEGRATION		
2. How much do attitudes and cultures within a company influence the successful development and co-ordination of an integrated construction programme?	Data (Examples)	
	Culture is a main influencer of successful programme development. Construction has a poorer planning culture than petrochemical or nuclear sectors. Cultures affect knowledge and understanding of programmes. The right attitude and culture is critical for programme development. Culture affects dissemination of supply chain strategy to their own leads. Company cultures critically influence the tender programme calibre. Poor cultures can allow programme provision to just be a 'tick-in-a-box'. Fragmented construction supply chains cause fragmented project cultures. Cultures have significant influence on approaches to programme development.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Company Culture and CPM Supply Chain Understanding Programme Reliability Collaborative Attitude to Programme Company Culture and CPM Supply Chain Understanding	Operational Cultures Shared Understanding Trust in Programmes Team Attitudes

Table 2. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 2

Question 3 related to the process of integrating individual supply chain trade programmes as part of the overall programme development. The emerging key concepts from the open coded categories from the transcript data are: 1) the requirement for a central programme direction for the disparate trade programmes, and 2) ownership of those individual programme contributions. Table 3 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME DEVELOPMENT, CO-ORDINATION AND INTEGRATION		
3. The development of construction programmes require many iterative passes around the supply chain. How well do you feel this process is managed?	Data (Examples)	
	The iterative development process not managed at all; it's hit-and-miss. Sub-contractor buy-in comes after they have an order, it's too late. Iterative programme development not done at tender stage. Common to get programme advice from a sub-contractor but then go with another. Iterative development is managed well if you afford the time and it's early enough. We are getting better [at programme development] but it requires commitment to it. It is managed well [relating to taking sub-contractor advice]. The process can be a tick-in-a-box [just to say it has been completed]. Poorly managed, compared to workshops I've seen in the past. Visibility and transparency of the iterative programme development process is poor.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts

	Programme - Evolution Supply Chain - Understanding Supply Chain - Early Involvement Supply Chain - Sub-Letting Team Collaboration Programme Development - Unstructured	Programme Direction Programme Ownership

Table 3. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 3

Question 4 related to a view of how current programme development and co-ordination processes could be improved. The emerging key concepts from the open coded categories from the transcript data are: 1) use of programme development frameworks, and 2) a supply chain framework to provide process consistency. Table 4 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME DEVELOPMENT, CO-ORDINATION AND INTEGRATION		
4. How do you feel the programme development and coordination process could be improved?	Data (Examples)	
	Need to move from tender through to construction with the same sub-contractors. Once the critical 'spine' is established use programme co-ordination workshops. Supply chain need to understand what really makes an activity work. Full process understanding: design details, procurement, resourcing. Engage with supply chain, get heavily involved, make them understand programme. Get the outline of the programme, the critical path, major elements of work. Using resource schedules and histograms. Front-end engagement with the supply chain is invaluable. Early involvement [supply chain]. Forming a clear, defined project programme strategy.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Supply Chain - Consistency Supply Chain - Consistency Supply Chain - Consistency Supply Chain - Consistency Supply Chain - Early Involvement Supply Chain - Early Involvement	Programme Framework Supply Chain Framework

Table 4. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 4

Question 5 related to what programme methods that the contracting organisations currently use to co-ordinate and integrate Critical Path Method programmes. The emerging key concepts from the open coded categories from the transcript data are: 1) programme development being generally supply chain led, and 2) programme integration being a relatively informal process. Table 5 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME PROCEDURES, METHODS AND TECHNIQUES		
5. What are the methods, techniques and protocols that construction organisations use to develop, co-ordinate and integrate critical path programmes?	Data (Examples)	
	Programme creation by main contractor for supply chain to follow. Supply chain involvement to familiarise them with the project. Understanding your supply chain and control of the supply chain. Stability of the supply chain. Supply chain advice. Internal team input and co-ordination. Programme certainty at sub-contract pre-order stage. Steer them [the supply chain] as best we can. Programme creation by sub-contractor for their supply chain to follow. Early [programme] workshops need to happen.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Programme - Evolution Supply Chain - Programme Resourcing Programme - Development (Structured) Programme - Commissioning Integration Team Collaboration Supply Chain - Engagement	Supply Chain Led Informal Processes

Table 5. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 5

Question 6 related to the responsibility of undertaking the project planning role. The emerging key concepts from the open coded categories from the transcript data are: 1) shared ownership of the role, and 2) evidence of diffused responsibility for undertaking the planning role. Table 6 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME PROCEDURES, METHODS AND TECHNIQUES		
6. Who has the responsibility for undertaking the project planning role at your organisation?	Data (Examples)	
	Initially the project planner; needs to be full team plan for buy-in. Project manager has overall responsibility. Planner evolves programme but no back-up [from the team]. Planner leads but it's a team effort as we can only deliver as a team. Planner controls programme, but input and development is the team. Planner; ultimate responsibility is the project manager and director. Dedicated planner, with project manager and team development. Project manager [at sub-contractor]. Planner, or project manager on smaller projects.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Programme - Creation Planning - Responsibility Planning - Responsibility Planning - Responsibility Planning Role - Project Manager Planning - Responsibility	Shared Ownership Diffused Responsibility

Table 6. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 6

Question 7 related to the process currently used to specifically integrate the sub-contract trade programmes. The emerging key concepts from the open coded categories from the transcript data are: 1) limited processes seem to exist for this crucial process in master programme development, and 2) the lack of a formal framework appeared to support the limited processes

currently used. Table 7 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME PROCEDURES, METHODS AND TECHNIQUES		
7. What processes do you follow to establish and integrate the various sub-contract trade sections of the construction programme?	Data (Examples)	
	Workshops and analysis of each programme iteration. Team familiarisation and collaboration. Develop a programme critical 'spine' of the four or five main trades. Aligning the supply chain with a [our] pre-set construction programme. Iterative passes of the [developing] programme around the supply chain. Supply chain experience. Programme creation by sub-contractor for their supply chain to follow. Communication and meetings to understand programme dependencies. Programme creation by main contractor for supply chain to follow. [Work] scope and interfaces identification then programme integration.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Team Collaboration Team Collaboration Communication with Supply Chain Programme - Site Co-ordination Programme - Integration Framework Programme - Development (Unstructured)	Limited Processes Lack of Framework

Table 7. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 7

Question 8 related to the programme scheduling software used by the contracting organisations. The emerging key concepts from the open coded categories from the transcript data are: 1) a standardised adoption of the main three planning software packages was evidenced. Table 8 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PLANNING SOFTWARE, TRAINING AND DEVELOPMENT		
8.What programme scheduling software is used at your organisation?	Data (Examples)	
	Currently ASTA Powerproject. Used Microsoft Project and Oracle Primavera. Used Project Commander. Microsoft Excel for short-term programming in a simple format. Microsoft Project and ASTA Powerproject. Oracle Primavera on power station work. ASTA Powerproject, work in Microsoft Project but transfer to ASTA. ASTA. Other variants but that's standard protocol here.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Planning Software - ASTA Powerproject Planning Software - ASTA Powerproject Planning Software - Microsoft Project Planning Software - Oracle Primavera Planning Software - ASTA Powerproject Planning Software - ASTA Powerproject	Standardisation

Table 8. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 8

Question 9 related to the existence of training in planning and programming techniques for the project staff at the organisations. The emerging key concepts from the open coded categories from the transcript data are: 1) a semi-formal approach to the provision of planning training appeared common, 2) an underlying apathy towards formal and structured planning training, and 3) didn't seem to be an awareness of a central responsibility towards provisioning that training; the feeling was it was somebody else's problem. Table 9 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PLANNING SOFTWARE, TRAINING AND DEVELOPMENT		
9. What planning and programming training, both formal and informal, is provided to those responsible for undertaking the planning role?	Data (Examples)	
	No general planning course, mainly experience from site. Software training from ASTA and Oracle. Generally self-taught, books, literature on planning. Nothing formal, mainly informal. Our graduates spend time in the planning department for experience. [Graduate] training is structured; formal and measureable. There isn't a structure [planning training pathway]. No formal training in terms of planning. We use internal people with site experience [as planners] who understand sequence. Not exactly sure; all staff can attend courses.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Planning Training - Lack of Structure Planning Training - Structured Placement Planning Training - Lack of Structure Planning Training - In-House Planning Training - College Planning Training - Lack of Structure	Semi-Formal Apathy and Low Interest Someone Else's Problem

Table 9. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 9

Question 10 related to evidence and examples of how the planning role specifically was nurtured and sustained at the organisations. The emerging key concepts from the open coded categories from the transcript data are: 1) appeared a low investment by companies in the planning role, and 2) what little there was appeared to be semi-formal such as by just having a planner, and ensuring there was always a planning presence, and replacing if they left. Table 10 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PLANNING SOFTWARE, TRAINING AND DEVELOPMENT		
10. How is the planning role nurtured and supported to allow stability, consistency and longevity within the organisation?	Data (Examples)	
	Generally, most contractors don't keep [planning] records. Programme is nurtured by keeping same key staff through a project. People think all you're doing [as a planner] is just colouring bars in. People see planning as a serious role, they see you stressed. It is changing now…project managers realise they get benefit. The business recognises it's an important discipline. There is a department lead…who is highly valued by the business. If a planner leaves they are replaced with another. I don't believe they [planners] are [supported], they seem on their own. I don't think we [managers] get close enough [to the planner].	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts

	Planning - Focus Via Techniques Planning - Support of Role Planner Allocation Programme - Site Co-ordination Programme - Managing Impact of Change Planning - Support of Role	Low Investment Semi-Formal

Table 10. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 10

Question 11 related to the development and implementation of a formal process framework for integrating the various sub-contractor trade programmes, similar to how the RIBA Plan of Work supports staged design development. The emerging key concepts from the open coded categories from the transcript data are: 1) need for strategic programme collaboration between project teams, and 2) the adding of a formal process to pre-construction (pre-planning) stage may be contingent on only being permissible by the client. Table 11 provides example statements from the interview data, main category per interviewee, and emerging concepts.

PROGRAMME PROCESS FRAMEWORK		
11. How do you feel a process similar to the RIBA's Plan of Work would be of use for developing a co-ordinated and integrated programme?	Data (Examples)	
	Especially [needed] for integrating sub-contractor programmes. Very useful, a set structure [for] risk, output rate, schedule uncertainty. Would provide consistency to programmes over current ad hoc [development]. Supply chain would understand it [programme development] better. Would we have time for that [process]? It would be a challenge. It would be hard [to do]; only if the client bought-in would it be a success. If we needed more time on pre-construction [to do this] clients wouldn't be interested. Clients would need to buy-in, but they would [benefit from] receiving a 'guarantee'. Work could be properly planned, a side-effect being a lot safer site as well. Stages [for programme development] might work, gets the whole team together. [Would provide] better integration and more in-depth programme development.	
	Main Category Per Interviewee (Via Open Coding)	Emerging Key Concepts
	Programme - Development (Structured) Team Understanding Programme - Integration Framework - Client Buy-In Programme - Integration Framework Programme - Strategy Team Input to Programme	Collaborative Strategy Contingent on Client

Table 11. Data Examples, Main Categories, and Emerging Key Concepts from responses to Question 11

DISCUSSION

Challenges of traditional CPM planning appear to be fundamentals such as basic understanding of CPM, the correct use of resourced programmes, and establishing the various stages of the programme. Poor grasp of these basics appears across the sample and makes it difficult to determine whether CPM is at fault, the users of CPM, or other reasons.

Cultures, shared understanding, trust in programmes, and team attitudes influenced the success of integrating programmes. Trade sub-programmes, crucial to the master programme,

require direction and ownership. Improvements to programme development and co-ordination require consistency and early team involvement via improved collaborative processes.

Current programme techniques to develop, co-ordinate, and integrate CPM programmes appear supply chain led and adopt informal processes. The responsibility is shared across the planner and project manager, sometimes the team, however this diffused responsibility can cause ownership issues. Integration of trade programmes lacks a framework to adhere to.

Electronic scheduling software is predominant at the organisations, providing a standardisation to the CPM programmes. Wider training in planning and programming skills is lacking, with a semiformal training structure. Apathy and low interest towards training was observed and the nurturing of the planning role appeared to have low investment and was semi-formal.

The suggestion of a process flow framework for CPM programme development, co-ordination, and integration appeared a requisite in contracting and was well understood. Its use as a collaboration tool was extolled, however it was deemed contingent on clients agreeing to something which may require more front-end time for programme development.

CONCLUSION

The results indicate that CPM planning operates within inconsistent and poorly-structured project environments at contracting organisations. There appears a lack of authoritative implementation, in contrast to the RIBA Plan of Work for design development (RIBA, 2013). Despite its common use, a culture of apathy towards understanding CPM, planning training, supporting and nurturing the planning role, programme integration, and responsibility was observed.

CPM is a dominant planning technique within construction project environments. However, there has been considerable evolution of more collaborative methodologies such as Lean Construction and Last Planner® System. These methodologies are critical of CPM, however it is crucial to understand whether CPM is disadvantaged by the environment within which it operates.

Further investigation is necessary to undertake a deeper and broader study into CPM within construction environments. Study across pre-construction and construction stages should give a greater understanding of CPM and its operating environment. Such results could allow a critical evaluation with modern methodologies to assist with informing the future application of CPM.

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THE TRANSFORMATION OF DISASTER RISK MANAGEMENT IN MALAYSIA, THE IMPLICATIONS AND SOLUTIONS

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Keywords: Resilience, Disaster, Flood, transformation, transition, Community role.

Abstract

Natural hazards in Malaysia are regularly happening, mainly flooding which occur every year during the monsoon season that are characterised by heavy and regular rainfall from roughly October to March and inadequate drainage in many urban areas. Flood events in Malaysia from 15th December 2014 to 3rd January 2015 affected more than 200,000 people while 21 were killed. This flood has been described as the worst flood in decades. Since the adoption of Sendai Framework for Disaster Risk Reduction SFDRR 2015-2030 (Sendai Framework) in Malaysia, the Disaster Management Committee which formerly held by the National Security Council (NSC) for central level transferred to the National Disaster Management Agency (NADMA)) whilst at the state and district level transferred to Malaysia Civil Defence Force. The transition made to focus on the implementation of the Community Based Disaster Risk Reduction (CBDRR) effort and the Civil Defence has been given the authority to train public during emergency, disaster and hostile attack. However, moving the management of Disaster Risk Reduction (DRR) from central level to national and community level face many challenges because public generally in Malaysia are relying on the government's response during disaster. This paper will focus on the risk associated with promoting the public, private and NGO's to assist in Disaster Risk Management (DRM) by draw an analysis of the Malaysian policy documents and expert interviews to map out current changes in governance. In addition, investigate data collected from local communities and individuals in two regions in Malaysia about the implication of the government call on community leaders to take a major role in the distribution of aid and assets during the disaster as it helps in the coordination process.

INTRODUCTION

Malaysia is located in Southeast Asia and has a tropical climate with warm weather all year round. Geographically, Malaysia is located outside the Pacific Ring of Fire and relatively free from certain severe crises found in neighboring countries (Unisdr, 2010). However, Malaysia is vulnerable to natural hazards including floods which have caused significant damages in the country, (Unisdr, 2010). The December 2014 -2015 flood events were the worst ever in the country's history, affecting more than half a million people. Many areas of the country that have never experienced floods before were also inundated and floodwater rose at an

unprecedented level. It is reported that the damage to infrastructure was estimated at $670 million U.S. dollars (RM2.851 billion) and 541,896 people were affected (CEDMHA, 2016) .

Disaster management in Malaysia has been considered as a government function and is largely based on top-down government-centered machinery (Chan, 1995). The National Security Council (NSC) coordinates disaster management in accordance with Directive No. 20, the "Policy and Mechanism on National Disaster Relief and Management" (CEDMHA, 2016). Since Malaysia adopted the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 (Sendai Framework) the Disaster Management Committee which formerly held by the National Security Council (NSC) for central level transferred to the National Disaster Management Agency (NADMA) whilst at the state and district level transferred to Malaysia Civil Defence Force. NADMA officially formed on 1st October 2015 with the consolidation of the Disaster Management Division of the National Security Council, Post- Flood Recovery Unit of the Prime Minister's Department and the Special Malaysia Disaster Assistance and Rescue Agency (SMART) (Seman, 2016). The transition made to focus on the implementation of Community Based Disaster Risk Reduction (CBDRR) effort and the Civil Defence has been given the authority to train public during emergency, disaster and hostile attack.

Furthermore, the Malaysian government is in the process of appointing the head of disaster management at the village and housing estates in preparation for strengthening standard operating procedures (SOPs) during floods (Ngah et al., 2017). This shifts towards a greater relevance of the 'local' in flood risk management (FRM) as a specific form of the 'localism' that has characterised many areas of recent governance practice in the United Kingdom (Coaffee, 2005). Localism is a form of decentralisation that favours the 'local' (in contrast to the regional, national, or international) as a level where decisions should be made and problems can be best addressed (Begg et al., 2015). However, moving the management of Disaster Risk Reduction (DRR) from central level to national and community level face many challenges because public generally in Malaysia are relying on the government's response during disaster. In addition, those locally at risk, including residents, businesses, farms, infrastructure etc, are gradually being transformed into risk managers or flood risk citizens (Begg et al., 2015). The paper provides a general overview about disasters risk management (DRM) in the past and during current flood events in Malaysia. This review includes insight into the current policies and strategies post disaster to understand the risk associated with promoting the public, private and NGO's to assist in DRM. Also provide an analysis of the expert interviews to map out current changes in governance. In addition, investigate data collected from local communities and individuals in two regions in Malaysia about the implication of the government call on community leaders to take a major role in the distribution of aid and assets during the disaster as it helps in the coordination process.

OVERVIEW FLOOD RISK MANAGEMENT (FRM) IN MALAYSIA

Flood management policies and strategies were developed by the colonialists and the current approach is modelled after them. The Department of Irrigation and Drainage (DID) is the agency responsible for flood management in Malaysia, was initially set up in 1932 by the British (Chan,

1995). Before the formation of the DID, river conservancy was the responsibility of the Public Works Department (PWD), another agency set-up by the British which focuses on engineering solutions (Chan, 1995). During the 1920s, a number of flood mitigation schemes were undertaken by the PWD, notably in Kuala Lumpur and Ipoh situated on the Kiang and Kinta Rivers respectively and only engineering solutions were used as the two rivers were canalised, embanked and shallow sections dredged periodically (DID, 1973). This essentially British culture of employing engineering solutions, a 'tech-fix' approach, continued right through independence until today (Chan, 1995). Since then, in Malaysia, official flood management strategy is mainly focused upon flood control measures classified as “Structural Flood Mitigation Measures”. For example, the construction of large artificial structures to control floods. However, the public have evolved traditional measures to reduce losses as well as adaptation to floods as unofficial measures. The flood management authorities in Malaysia recognise that a comprehensive method employing both structural and non- structural measures would be hugely beneficial. However, politics and economic considerations often significantly reduces the application of non-structural measures and this has limited overall effectiveness (Chan, 1999). In Peninsular Malaysia, notwithstanding the fact that individuals are responsible for their own lives and properties, the responsibility of flood management rests largely with government departments and agencies (Chan, 1995). Flood problems before 1973 were tackled by large number of government agencies involved with flood operations from forecasting to rehabilitation. However, no specific government agency was solely responsible for overall flood management as each agency operated within its own jurisdiction (Chan, 1995).

Since the 1971, flood management in Malaysia became a formalised responsibility of the government and the Department of Irrigation and Drainage . However, the DID was more interested in agricultural development than flood management because the river conservancy and flood mitigation was assigned relatively low priority by the DID (Chan, 1995). In December 21, 1971, the Permanent Flood Control Commission was established by a Cabinet decision to study short-term measures to prevent the occurrence of floods and long-term measures for flood mitigation. The main objective of the Flood Commission is prevention of the flood rather than cure. The main terms are; firstly, to take measures for flood control and to reduce the occurrence of floods and secondly, in the event of floods, to minimise damage and loss of life and property (Chong Wing, 2016).

The recurring flood in Malaysia have made legislation for adequate flood hazard management critical including direct and indirect legislation to address river use, water, mining and land (InterWorks, 1998). However, some older legislation created clashes between the federal and state over flood management policies in Malaysia such as “Water Enactment of 1929“and the “National Land Code of 1965” which give prerogative to the state (provincial level) for water use (InterWorks, 1998). For instance, a state may try to develop land near a river even though federal flood control measures may deem that the land should be reserved as a flood plain (InterWorks, 1998). Furthermore, it is stated that the commonest failures in disaster management concerns the lack of understanding of the social and cultural mitigation measures of the local community (Davis, 1981). As flood hazard management in Malaysia is very much a function of the government and its appointed agencies such as the DID, the MMS, the police,

and the local authorities, which explains why educated public hold the government responsible for flood occurrences (Chan, 1995).

The main problem in Malaysia is the law enforcement, as many legislations relate to flood control such as the “Mining Enactment of 1929”, the “Drainage Works Ordinance of 1954”, the “Land Conservation Act of 1960” are not significantly forceful (InterWorks, 1998). In Malaysia, flood hazard reduction largely depends on how effective flood hazard institutions are. Flood hazard institutions can either reduce flood hazards through effective management or amplify them through mismanagement or failures (Chan, 1995). Thus, flood hazard management will be effective if the government control and enforce flood reduction programmes through its tools including Laws, regulations, administrative jurisdiction, enforcement powers, duties and responsibilities, and interventionary powers (Chan, 1995).

CURRENT POLICIES AND STRATEGIES POST DISASTER

Following collapse of Highland Towers Condominium in Hulu Kelang, Selangor on December 11th 1993, where 48 people was killed, 1993, the Cabinet meeting on May 18th 1994 decided to form an organization or a mechanism of Great Inland Disaster Management on scene which is to be functioning under the National Security Division(BKN), Prime Minister Department(JPM) (NSC, 1998). In 1997 the National Security Council Directive No 20 was established as the main guideline for disaster management in Malaysia and to provide a guideline to all agencies on their roles and functions during disaster. It is complemented by other sectoral legislation in forming a comprehensive framework, including the Land Conservation Act; Environmental Quality Act; Town and Country Planning Act; Irrigation and Drainage Act; and Uniform Building by Law (Wahab, 2013).

The Directive 20 outline the mechanism of Disaster management more thoroughly covers the preceding stage, during and after a disaster. Every (Wahab, 2013)agency involved in disaster management are responsible for implementing their respective roles in accordance with this Direction. Furthermore, The existence of a Disaster Management and Relief policy will help all sectors involved to carry out their mission with more orderly and coordinated, thus avoiding any waste of energy and time, confusion, conflict and contradiction or conflict of interest while working in a disaster (NSC, 1998). According to the Directive 20 the disaster management handling will be regulated based upon the disaster level as mentioned below (Badruddin, 2012). Figure 1 shows the three levels:

Level I Disaster:
Disasters controlled at locally that has no potential for further outbreak. It is expected to be less complex and may result in small loss of lives and properties.
Level II Disaster:
This is a more serious event happening in a larger area or exceeding two districts and has potential for an outbreak. This would cause death and damage to a large number of property.
Level III Disaster

Originated from level II Disaster and is characterised by extreme complexity or the disaster has taken place through wide area or exceeding two districts. This will be handled by the central authorities at the federal level with or without foreign help.

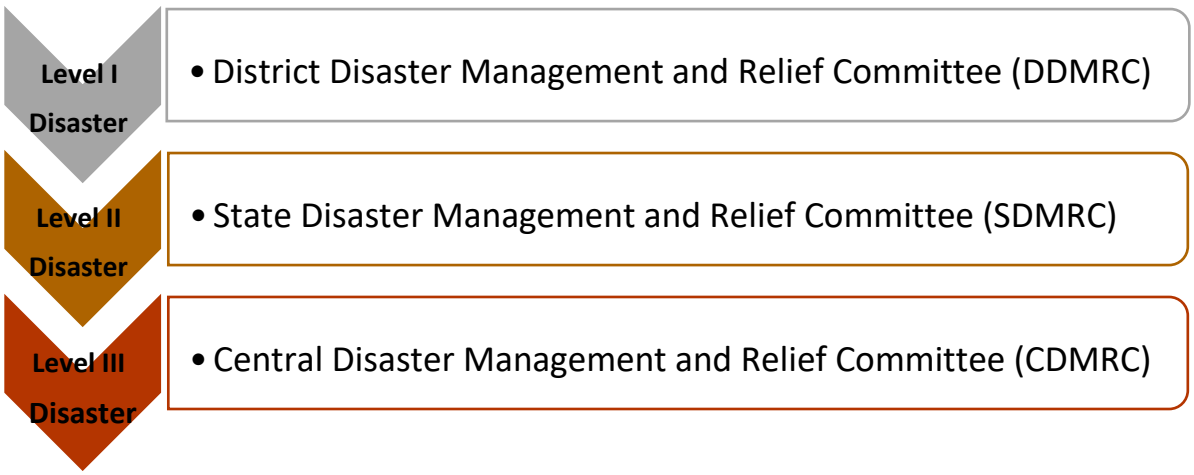

Figure 1: Disaster Management Organization Levels in Malaysia (CEDMHA, 2016)

A research carried out by Badruddin, 2012 to determine the level of understanding, knowledge and practice of Directive No.20 of disaster management preparedness involving several agencies in Kedah, Malaysia found out that Directive 20 is no doubt an effective mechanism on managing disaster and the relief effort. However, this mechanism is not being put to extreme test as Malaysia is lucky to be located in a relatively safe part of the world away from many major natural disasters. Furthermore, the research finds that the disaster management in Malaysia is rather reactive than proactive as in many instances the response is only after disaster has occurred (Badruddin, 2012). The study concludes that there is a need for a comprehensive approach to cover all aspects of the disaster management cycle in order to reduce the occurrence of potential disasters. Also, there is need to include an appropriate balance of each component of response, recovery, development, prevention, mitigation and preparedness (Badruddin, 2012). On the other hand, Malaysia organised the third Asian Ministerial Conference on Disaster Risk Reduction in Kuala Lumpur in 2008 and signed the Association of Southeast Asian Nations ASEAN Agreement on Disaster Management and Emergency Response (AADMER) that entered into force in 2009. The agreement is a further testament of ASEAN's commitment to systematically address and develop formal legal and logistical arrangements to respond to disasters in the region (National Security Council, 2012). The country has been participating in all previous AMCDRR as well as its Global Platforms in Geneva and supports various programmes and campaigns organised by International Strategy for Disaster Reduction (ISDR) (Wahab, 2011). DRM in Malaysia have been placed under the Disaster Management and Relief Committee and it consists at the central, state and district levels to manage disaster more effectively (Figure 1). Meanwhile the National Security Council (MKN) is the lead agency for disaster management in the country where the MKN has the responsibility to coordinate, establish and ensure the policies and the disaster management mechanism are observed and implemented at all levels based on Directive No.20 (NSC, 1998).

TRANSITION TO COMMUNITY-BASED DISASTER RISK REDUCTION

"Community-based Disaster Risk Management (CBDRM) is a process in which at-risk communities are actively engaged in the identification, analysis, treatment, monitoring and evaluation of disaster risks in order to reduce their vulnerabilities and enhance their capacities (ADPC 2003). This means that people are at the heart of decision-making and implementation of disaster risk management activities. The involvement of most vulnerable social groups is considered as paramount in this process, while the support of the least vulnerable groups is necessary for successful implementation." (Abarquez & Murshed, 2004)

Malaysia has been adopting several strategies to advance progress in mainstreaming DRR and incorporated it into land use planning system and integrated into the overall national development plans and projects for sustainable development (Wahab, 2011). Hyogo Framework for Action 2005-2015 (HFA) which was adopted in Malaysia is promoting the community-based training initiatives and consider the role of local volunteers as appropriate to enhance local capacities to mitigate and cope with disasters (UNISDR, 2005). Three cities in Malaysia were named Role Model Cities as part of the United Nations-led "Making Resilient Cities" campaign including Kuala Lumpur, Putrajaya and Melaka. The camping was launched during Malaysia's National Disaster Awareness Day celebrations from 18 to 19 February 2011 (Salim, 2011). The cities were chosen for their ability to take up ten essential actions that reduce disaster risk. These actions include: investing in and maintaining, critical infrastructure; regularly assessing the safety of schools and health facilities; and ensuring education programmes and training on disaster risk reduction (Salim, 2011).

"The people of Malaysia are aware of the increasing risks of disasters, especially due to global climate change. We are dedicated to implementing the Hyogo Framework and we also look forward to see global progress in reducing disaster risks at the third Global Platform on Disaster Reduction in May." Mr. Muhyiddin bin Mohd Yassin[3]

In Malaysia, the state governments and state agencies received funds from the federal government and are responsible for tackling flood problems in their own states respectively. However, because of political, economic, physiographic and other differences, some states may have different policies and strategies in managing floods other than those prescribed by the federal government (Chan, 1995). Furthermore, without the active involvement and participation of the vulnerable communities' response, the local authorities may not be able to achieve a great success in disaster reduction and preparedness as effective disaster risk reduction needs an action by all vulnerable individuals, families, communities and organizations (Kafle & Murshed, 2006). A report on Community-based Disaster Management for Local Authorities done by Asian Disaster Preparedness Centre (ADPC)[4] stated that limited facilities within local authorities including the technical, human and financial resources, which may not be sufficient to implement disaster risk reduction activities amongst all vulnerable

[3] Malaysia's Deputy Prime Minister and Minister of Education launched the campaign at the Melaka International Trade Centre, attended by Government leaders, city mayors, academia and civil society.

[4] Asian Disaster Preparedness Centre ADPC established in 1986 is a regional, inter-governmental, non-profit organization and resource centre to promote safer communities and sustainable development through the reduction of the impact of disasters.

communities. Therefore, it is essential that the local authorities mobilise support from various civil society institutions and involve larger communities (Kafle & Murshed, 2006).

The National progress report on the implementation of the Hyogo Framework for Action (2009-2011) stated the Since the 1990s, the Malaysian government has put in place policy, infrastructure and operational mechanism that transcend from the national, state and district levels to ensure cohesive participation and involvement of various government agencies and non-government sector in disaster management (Wahab, 2011). According to this report, the Community-based Disaster Management Programme has been implemented through collaboration of multi-level agencies in several states in order to enhance the resilience of communities to disasters. There were activities designed to help community stakeholders to determine their levels of awareness and capacity on disaster risks and community-specific disaster management plan (Wahab, 2011). However, There are many challenges faced by state crisis management agencies, the lack of fund for training to conduct disaster preparedness and readiness for the local community is one of them (Dorasamy et al., 2010).

RESEARCH REVIEW AND METHODOLOGY

This study used a mixed method research approach based on literature on disaster management in Malaysia and it focus on the risk associated with the transformation of DRM in Malaysia, and promoting the Community-Based Disaster Risk Reduction (CBDRR) by draw an analysis of the Malaysian policy documents and expert interviews to map out current changes in governance. In addition, a survey conducted with a number of households in Kelantan and Temerloh regions in Malaysia who experienced flood events in December 2014 and January 2015.

The research is addressing disaster risk management and because of its wide scope, the research questions narrowed down (Rambau, 2011) and mixed approach chosen because data collected through the questionnaire has some limitations. In this respect, to address these limitations the study employed interviews with specialists with various expertise on disaster management which resulted in gathering data from some key elements such as policy makers and local authorities' agencies, also focusing on the contribution that local communities could make to disaster risk reduction.

The advantages of using the mixed methods by combining quantitative and qualitative research enables to evaluate and investigate the complexity of research questions (Onwuegbuzie & Leech, 2004) about the implication of transforming of Disaster Risk Management in Malaysia from state level to community level. The approach of chosen method helped to obtain more details and informative data to assess the community learning on risk management that took place during the 2014-2015 events and identify ways in which the community response to flood can be improved. Additionally, mixed method helped to develop a conceptual framework to validate quantitative results by linking the information extracted from the qualitative data

collected from interviews, and to construct findings from qualitative data that can be utilised to analyse quantitative data (Madey, 1982). the questionnaire and the interview questions are both designed to reflect the rationale for undertaking mixed methods research and clearly demonstrate the qualitative and quantitative dimensions of the project (Madey, 1982).

Research Method

A literature review was performed to review literature and reports on DRR and DRM from government agencies in Malaysia, such as the National Security Council (NSC), the Public Works Department (PWD), the Drainage and Irrigation Department (DID), the Welfare Department (WD), the Statistics Department (SD), and other agencies/organizations. The review focus on identifying the risk associated with promoting the public, private and NGO's to assist in DRM by draw an analysis of the Malaysian policy documents and expert interviews to map out current changes in governance. Furthermore, the questionnaire and semistructured interview with local authorities, community leaders and local volunteers and residents in Kelantan on the northeast of Peninsular Malaysia and Temerloh in the Central of Pahang, to investigate the implication of the government call on community leaders to take a major role in the distribution of aid and assets during the disaster as it helps in the coordination process. Semi-structured interviews of key actors: a list of questions was prepared beforehand, but additional questions were asked as the interviews progressed, and all interviews were tape-recorded and transcribed. These interviews were carried out at the end of the research period, and their purpose was primarily to clarify information and issues that influenced the research.

Interviewee Number	Organisation /Profession
Interviewee 1	Member of the Policy Planning and Coordination Division, Malaysia Civil Defence Force
Interviewee 2	Member of the Communication and Rescue Organisation in Pasir Mas
Interviewee 3	Member of the faculty of Social science and Humanities, The National University of Malaysia
Interviewee 4	Member of Civil Defence in Kuala Krai
Interviewee 5	Member of Kuala Krai District office
Interviewee 6	Member of School chancellors in Kuala Krai
Interviewee 7	Member of Civil Defence in Gua Musang
Interviewee 8	Member of Civil Defence in Temerloh, Pahang
Interviewee 9	Member of Temerloh district office

Interviewee Sampling: the criteria for selecting participants was based on selecting individuals who were qualified to give constructive responses to research questions. It is notable that the interview participants expressed a preference towards being interviewed as an “individual” participant rather than as a representative of an organisation. Thus, the interview participants view the ethical nature of interview questions to pertain to personal experiences rather than being representative of an entity that they are a part of. All interviewees were offered anonymity to encourage open and frank dialogue, and the permission of individuals to quote their responses was obtained. Each interview lasted for approximately 30 to 45 minutes. Hand-

written notes were taken during or after the interview, and all interviews were recorded and transcribed. The interviews focused on three broad questions:

1. How effective was the mechanism and implementation Directive No.20 during 2014/15 flood events?
2. What are the actions taken after 2014 floods events in Malaysia to achieve an effective disaster management system that covers each component of response, development, prevention, mitigation and preparedness?
3. How the Malaysian authorities is going to implement CBDRR approach that have been practiced by Japanese, Philippines and Indonesian?

RESEARCH RESULTS

The Malaysian government is in the process to transform its DRM following the frequency of natural hazards in the past decades. This transformation includes local communities' empowerment and role on DRM. It is clear that the Malaysian government agencies and NGOs are making efforts to train and raise awareness of flood risks within local communities and schools. however, raising local communities' awareness to flood risk and management needs sufficient resources and facilities funding and flood risk measures should be communicated clearly to community leaders and volunteers in order to make the participation of the public in an early stage most effective. In terms of policies, Directive 20 is an effective mechanism on managing disaster and the relief effort, however, there is a need for a comprehensive approach to cover all aspects of the disaster management cycle in order to reduce the occurrence of potential disasters. Furthermore, there are plans to implement the Communitybased Disaster Management Programme through collaboration of multi-level agencies in several states to enhance the resilience of communities to disasters.

The survey carried out in in Kelantan on the northeast of Peninsular Malaysia and Temerloh in the Central of Pahang, found that more than half of the responders have been living significant period of time in the regions where flood risks' concerns increased in the past decades. However, it is obvious that local people have their own measures to reduce the impact of flood on themselves and their assets. A huge percentage of the responders show their love of awareness to protect their property and themselves during disaster or emergency. However, lack of funds to train more people reflects on the number of people who are not ready for severe flood events. In terms of level of preparedness and warning system, more than a half of the residents received flood warning messages which relatively low and indicates that there are more people vulnerable in these regions. However, the percentage of residents with level of awareness of safety measures is relatively high and shows that local people have their own measures to mitigate flood risks. The Sendai Framework for Disaster Risk Reduction 2015 - 2030, recognizes that there is a lot of knowledge across stakeholders and local communities that needs to be managed effectively and leveraged (UNISDR, 2015). This question aims to understand to what extent local community's leaders and individuals are willing to share their flood knowledge. Finally, the survey shows that the majority of responders are already sharing

their knowledge of flood mitigation with local authorities. However, half of the residents think that they should be more involved in decision making and 33% think it is not necessary to be involved on mitigation measures with local authorities.

Local communities Survey

The study area focused on regions affected by the worst floods in Malaysia, such as Kelantan on the northeast of Peninsular Malaysia and Temerloh in the Central of Pahang. The study was undertaken in August 2017 and the criteria based on individuals' unit of analysis of Malaysian citizens. In order to gain equal participation from the citizens of both regions, the questionnaires were sent to 100 household members in 4 cities and 5 villages and responders were randomly selected. The data analysed through descriptive statistics data analysis using Microsoft Excel to identify the frequency and percentage of the questions. The questions are divided in five sections:

Section 1: General information about responders.

The characteristics of the responders as shown in Table 1, comprise of 52% male and 48% female while the age is ranged between 18 to over 60 years old. The percentage of responders age groups are relatively close and ranged between 16% to 24%. That shows the balance of selection as an important factor to generalisability of the findings. 74% of the responders are married and slightly more than half (56%) of the household level of income within RM1000RM4999 which can be classified in moderate economic status as lower-middle income threshold. The education level of the responders shows more than 72% of them are hold a secondary education level and 16% are primary holders. Only 12 % are with university degree. The survey shows that 67% of the responders have access to the internet. The general indication is that 55% of the responders have been living significant periods of time in the area for more than 20 years and 24% between 11 to 20 years. Therefore, the data has provided useful information that can be used against other questions. The responders were asked if they have received training in the First Aid within the past 5 years, the results are concerning as 57% has not been trained and 6% are not sure.

Profile		Percentage(%)	Profile		Percentage(%)
Age Group			Income Level		
	18-30	22		Less RM999	31
	31-40	16		RM1000-RM4999	56
	41-50	24		RM5000RM10,000	6
	51-60	20		No Answer	7
	60 and over	18			0
Gender			Education Level		
	Female	48		Primary	16
	Male	52		Secondary	72
				University	12

Marital Status			Internet Access		
	Single	16		Yes	67
	Married	74		No	33
	Divorced	4		No answer	0
	Widowed	1			
	No answer	5			
How long lived at current property			trained in First Aid (within the last 5 years)		
	0-5 years	15		Yes	37
	5-10 years	6		No	57
	11-20 years	24		Not sure	6
	20+ years	55			

Table 1: Responders' Profile

Section 2: Responders experience on Disasters

During their residency, the majority of residents expressed their concern about the growth of flood risks in their regions. The collected data suggests that people who lived in these areas for more than 20 years are witnessing the sever flood events increasing every year. The second question designed to understand if the residents take any actions as a result of receiving a warning of flooding and to figure out the level of awareness to protect themselves and their property during disaster or emergency. The majority of the responders have their own measures to reduce the impact of flood on them and their properties, however, about 23% shows lack of experience to deal with sever flood event. This therefore relates to the literature findings about the lack of funds for training to conduct disaster preparedness for local community (Dorasamy et al., 2010).

Section 3: Perceived Disaster Preparedness.

The responders were asked if they are registered to receive flood warning and the aims to understand whether the residents received relevant information about the disaster in time. The answer shows that only 61% of the responders received timely warning about the disasters in order to take necessary steps to protect themselves, their family, belongings and home. However, nearly 39% of the responders who have indicated that they do not receive flood warning shows that people are more vulnerable. This is because the effect of floods in less developed area has lot of problems with emergency response and early warning preparation (Khan et al., 2014). In terms of residents' level of awareness of safety measures they have to take during disaster or emergency, interestingly, a majority of 96% of the responders have shown their understanding of actions that have to be taken when they receive a flood warning. This matches the research findings by Badruddin (2012) to determine the level of understanding, knowledge of Directive No.20 of disaster management preparedness.

Section 4: Awareness

Regarding the current flood mitigation measures in place within your community, the questionnaire results indicate that half of the responders (54%) are aware of the flood

mitigation measures in place within their area. However, the fact that there are 31% of residents who are not aware of any mitigation measures for natural hazards and 15% who are not sure about them. This indicates that there is awareness problem among local communities and there is a need to develop and implement education and awareness programs amongst local communities and individuals to enhance understanding, preparedness, and opportunities for mitigation (UNISDR, 2013). It terms of understanding any information disseminated by Civil Defence, Mercy Malaysia and local authorities, such as flood maps and warning systems, it is clear from the responders that the majority of people (78%) are able to understand flooding information provided by local authority's agencies, whilst 17% found it incomprehensible and 5% said that they are not sure which relates to inability to have an access to this information or to the internet. This finding indicates that the HFA which was adopted in Malaysia is not fully implemented on all regions.

Section 5: Share knowledge and participation with local authorities

The SFDRR recognizes that there is a lot of knowledge across stakeholders and local communities that needs to be managed effectively and leveraged (UNISDR, 2015). The responders were asked if they share their experience and knowledge of flood mitigation measures with local authorities or NGOs to understand to what extent individuals and community leaders are willing to share their knowledge. Surprisingly, 75% of the responders are already sharing their knowledge of flood mitigation with local authorities, whilst 16% said that they don't and 9 % answered not sure. Additionally, local people were asked if they are welling to be involved in decision making with local authorities such as the Civil Defence regarding the planning and development of flood mitigation measures in their areas. It is interesting to see that only 52% of the residents think that they should be more involved in decision making regarding flood mitigation measures whist 75% of them said previously that they share their knowledge with local authorities' agencies. From the findings it is noted that 33% think it is not necessary to be involved on mitigation measures with local authorities and 15% are not sure if this is the way forward.

DISCUSSION

The participants on the interviews were asked a range of questions in order to highlight the risk associated with promoting the public, private and NGO's to assist in DRM and what are the activities that the Malaysian authorities is going adopt to reduce the risk of implementing the CBDRR.

Community Awareness

In Malaysia, the flood risks have become more severe in recent years and the impact on victims is huge in flood prone areas. Therefore, there are calls to adopt CBDRR as a Bottomup approach to encourage a process of public participation in every aspect of policy formation and evaluation. Interviewees 1,2,4, 7 and 8 said that they are trying to educate the public and raise the awareness of flood risks within flood prone areas. However, the lack of facilities and funds

from the central government makes their efforts limited within Kelantan and Temerloh regions. In this instance, many local and international NGOs are taking their role to educate community leaders and organise training sessions for students at schools. For example, Mercy Malaysia[5] is involved in Kelantan on the School Preparedness Program, where they teach the students and raise the awareness of disasters and risks of floods (interviewee 2). Generally, local people learn from their experience how to protect themselves and their assets and the local volunteers are trying to learn from their past mistakes and make things better when disaster happen. Interviewee 2 sated that they try to get the new generation involved as volunteers and they visit schools and try to encourage them to participate because most of the members of Communication and Rescue Organisation are in their 30s, 40s and over 50s.

> Most of the people on this region have the experience, skills and prepared to deal with flood events, for examples, they have boats and store foods. However, sometimes people stuck in their homes in villages and they call us for help.
>
> (i2. Member of the Communication and Rescue Organisation in Pasir Mas)

Raising community awareness of flood risks, particularly within local flood prone areas, should be initiated as a priority and an effective communication and engagement with local communities is important in order to set realistic expectations and achievable outcomes of local FRM (Arthur, 2013). In Temerloh district for instance, Stakeholders are in agreement with local authority to give aid and support to vulnerable people during flood events and there is a good relationship and communication between general public and the local authority's agencies. For example, Civil Defence organise 3 open days during the year for public to be engaged with the civil defence efforts to train and support local communities (interviewee 8). Furthermore, mostly each household in Kelantan and Termerloh have smart phones and most of the people are registered to receive the disaster alert warning from local authorities. Also, local people are encouraged to share information with local agencies involved on training and rescue operations (interviewee 2). Thus, it is believed that people in these regions have the experience and prepared to face any flood events in the future as they are listening to flood warning better than before and they are aware of flood risks on their lives and their assets (interviewee 2,9).

Lessons learnt after December 2014 -2015 Flood Events

There are number of changes happened in the year 2015 on FRM in Malaysia where the Disaster Management Secretariat moved from National Security Council to National Disaster Management Agency and Malaysia Civil Defence Force (interviewee 1). Furthermore, more efforts to enhance the role of local communities and volunteers by establishing the Civil Defence Emergency Response Team within local communities, NGO, other government agencies and the private sectors (interviewees 1,4 and 7). Interview 3 stated that several studies have been performed by local and foreign universities to enhance the capabilities of Disaster Management concept in Malaysia and science and technology approach towards mitigation and prevention was adopted. This statement demonstrates the importance of research to define the effectiveness of flood damage mitigation measures, such information is

[5] MERCY Malaysia is a non-profit organisation focusing on providing medical relief, sustainable health related development and risk reduction activities for vulnerable communities in both crisis and non-crisis situations.

vital for policy-makers who are involved in the establishment of FRM policies in order to reduce flood vulnerability, and households and businesses who want to reduce the flood risk to their properties (Poussin et al., 2015).

> Ministry of Higher Education allocated millions of Ringgit from the government fund for researchers and other organisation also spend money to teach the general public how to manage and share information and how to evacuate during flood events.
>
> (i3. Member of the faculty of Social science and Humanities, NUM)

People on affected areas of December 2014 and January 2015 flood events learnt that being better prepared at the community level, is very important as the local people are the first responder in any disaster, therefore, training and raising local communities for flood risks and management is vital to be well-prepared to face the calamity (interviewee 7). Regarding coordination between several agencies involved during and after the disaster, the main challenges faced local authorities was the lack of communication skills and coordination between local and international agencies. Therefore, local authority managed to establish a sound system of coordination among agencies in search and rescue operations as well as relief and rehabilitation (interviewee 7).

> There is new establishment of the National Disaster Management which responsible about the coordination between all agencies and monitoring the river levels.
>
> (i5. Member of Kuala Krai District office)

In addition, the Malaysian government in 2017 start the process of appointing the head of disaster management at the villages and housing estates in order to strengthening the standard operating procedures (SOPs) during floods event (Ngah et al., 2017). Arguably, by considering the local context and the needs of local actors, more democratic and better decision-making processes can be taking to strength the role of the local authority and the need to involve actors at the local level (Begg et al., 2015). The current move and changes on Malaysian approach to manage flood risks is to ensure that management of flood victims could be made more quickly and thoroughly, said Minister in the Prime Minister's Department, Datuk Seri Shahidan Kassim, (Ngah et al., 2017).

Challenges to adopt the Community Based Disaster Risk Reduction (CBDRR)

The 2014 flood was enormous and beyond expectation and the guideline of Directive No'20 was followed and there are several efforts from the Federal Government to relief the flood. It could be said that the mechanism of Directive no20 is effective but there is still shortage in skills and efforts to prevent and mitigate enormous flood (interviewee 1). Also, it is stated that the function of Civil Defence Force is to instruct the public regarding civil defence and equip and train them to cope with any civil defence emergency (Laws of Malaysia, 2016). However, concern has been empowering at-risk communities with the skills and tools they need to protect themselves and their assets from harm (interviewee 1). Therefore, training should focus on first aid, search and rescue, firefighting, and distribution of relief supplies. Teams are also provided with the tools they need as first responders. After their training, the Civil Defence

Emergency Response Team (CDERT) members return to their villages and teach other members of their community the techniques they have learned.

In terms of adopting the Community-Based Disaster Risk Reduction (CBDRR), this shifts in responsibility might not reflect the perception of the local actors that are intended to be involved and with shifts towards localism requiring the general public to change the way in which they perceive their role in society (Begg et al., 2015). Therefore, it is the role of Civil Defence Force to promote the CBDRR concept within the community levels (interviewee 1).
Main steps to be taken are (interviewee 1):

- Raise the awareness and understanding of flood risks and early evacuation.
- promote a strategic and systematic approach to reducing vulnerabilities through the formation of CBDRR within the local communities
- Promote the implementation of local disaster preparedness programmes to community leaders, volunteer groups and in schools.
- Empower the function and roles of the communities upon disaster to assist vulnerable people and whom needs support.

However, there is likelihood that some vulnerable communities will not be able to handle the opportunities of implementing the CBDRR, whilst others will be able to take advantage of the scope to empower local actions and decision making process (Begg et al., 2015). In this instance, interviewee 1 stated that there will be some vulnerable communities unable to be reached within a short period. However, with proper planning, coordination and support for central government agencies, NGO's, private sectors and the communities themselves, the CBDRR effort could be a success in reducing the risk of disaster. The Malaysian government urged community leaders to take a major role in the distribution of aid and assets during the disaster and local community should understand the standard operating procedures (SOPs) during floods to avoid problems arising (AstroAwani, 2017). Minister in the Prime Minister's Department, Datuk Seri Shahidan Kassim said the CDERT was set up at community level to identify assets, food aid and daily necessities shortly after the disaster.

> If the community finds a problem or lack of assets, the district or community committee should identify the assets available from the Public Works Department, the Fire and Rescue Department, Rela, the Civil Defence Force, the Malaysian Armed Forces and the police.
>
> Datuk Seri Shahidan Kassim, Minister in the Prime Minister's Department (AstroAwani, 2017).

However, the implementation of the CBDRR may associated with risk of inequality or more vulnerabilities, mainly in rural communities because lack of funding and other forms of support available to build knowledge and motivation (Begg et al., 2015). It is stated that there is awareness of the inequality issue since the Malaysian government' agencies can not satisfy the needs of general public mainly in rural areas, however, there are steps to consider in promoting the FRM such as localities, culture, difference of races and ethnics, livelihood and other factors (interviewee 1).

CONCLUSION

The literature review on FRM in Malaysia and the current policies shows that there is a lack power and funds to reduce the impact and mitigation enormous flood events. Empowering the public awareness to flood risk and benefits of local flood knowledge could be achieved by the implementation of CBDRR. That is why Civil Defence Forces has reached different approaches in the recent years for flood mitigation measures that focus on improving the local community engagement and improving the community risk awareness for an effective flood preparation. Furthermore, the study shows that the members of Civil Defence Forces believe that local communities and individuals learnt from their experience with past flood events how to protect themselves and their assets and the local volunteers are trying to learn from their past mistakes and make things better when disaster happen.

The results of the survey carried out in in Kelantan on the northeast of Peninsular Malaysia and Temerloh in the Central of Pahang, found that local people have their own measures to reduce the impact of flood on themselves and their assets. However, lack of funds to train more people reflects on the number of people who are not ready for severe flood events. Furthermore, the percentage of residents with level of awareness of safety measures is relatively high and the majority of responders are already sharing their knowledge of flood mitigation with local authorities. On the other hand, there are calls from the Malaysian government to adopt the Community-based Disaster Management Programme through collaboration of multi-level agencies in several states to enhance the resilience of communities to disasters. However, there are concerns that local communities and individuals have different attitude toward such effort and public can't be forced to involved on this approach. Also, the fares of inequality has been increasingly recognised as important to how FRM is to be exercised (Begg et al., 2015). In this instance, the Civil Defence Forces recognise the implications of adopting the Community-Based Disaster Risk Reduction, and set number of measures to promote the concept within the community levels.

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Certification and Automation

THE IMPACT OF DANISH GREEN BUILDING CERTIFICATION (DGNB) ON ORGANIZATIONS WORK PROCESSES AND DOCUMENTATION WORK

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Abstract

DGNB (Danish Green Building Certification) is a certification which is adapted to Danish legislation and norms from a German certification for sustainable construction. Today there is an increasing number of partners involved in this certification, and many discussions evolves around the effects of producing a DGNB certification of a building. To achieve the chosen certification level (silver, gold or platinum), extensive documentation of tests, calculations and processes is required. Traditionally, production of documentation is integrated into or sidelines the (physical) construction process, but a DGNB certification will require implementation of new tasks, processes, and procedures. The introduction of new practical tasks, as well as through a development of visibility and responsibility for production and handling of documentation, a DGNB certification will by producing a common database for all DGNB documentation, transform the involved organizations and open for changes in construction practices and building design. Our research is aimed to help qualify and improve a DGNB certification, by making the involved parties, including builders, consultants, and contractors, able to gain an insight into the various challenges. This will help to draw up a plan for work tasks involved, and create efficient modes of work, to achieve the respective grades and criteria of a DGNB certified building. A qualitative method has been used in the form of literacy assessment and semi structured interviews conducted with a DGNB auditor and an architect involved in DGNB certification processes, along with a questionnaire that allows researchers to investigate the challenges of organizations to fulfill the demands for documentation. The interviews are analyzed to detect and unfold challenging issues of the organizations. The discussion presents experiences and issues that were challenged within a DGNB certification process, pointing out some key factors in improving workflows and improving the effectiveness of the documentation, e.g. increasing the interdisciplinary interaction between involved actors early in the design phase.

INTRODUCTION

The first Danish certification system for sustainable buildings, was launched by the Green Building Council Denmark (DK-GBC) in 2012. DK-GBC adapted the German system DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) due to its emphasis on climate, holistic approach and promotion of innovation as a strategy for 'green buildings'. The DGNB's

definition of sustainable buildings is originated from discussions started by 'Our Common Future Report, 1987' (the Brundtland Report) (DK-GBC, 2012), which stresses the three dimensions: environmental, social and economic as basic qualities (Brundtland, 1987). They inscribe a multiplicity of single factors to be included in the processes of planning and deciding qualities and performance of sustainable buildings (Ahn et al., 2013).

The certification process: Change and challenges

DGNB certification is a system of norms, procedures and points that corresponds with the Danish Building Regulation, it is designed to assist and motivate parties to engage in developing sustainable buildings. As the concept of "sustainable buildings" is still relatively new in terms of understanding how a variety of sustainability qualities are produced by a multitude of interrelated decisions, hence systematic evaluations of experiences from certification processes are few (Worm, Amdi Schjødt et al., 2014). Our research is undertaken to produce information and knowledge about the challenges and benefit of engaging and motivating stakeholders in DGNB certification processes. Many parties in the building industry seem to have limited motivation to engage in DGNB certification, and equivalates certifications processes with problems and challenges that do not pay off. According to Denmark Statistics in 2015, over 5.5 million m^2 were constructed in Denmark while only 45 buildings were certificated by Dk-GBC ('DK-GBC Certificated projects', 2018). The building industry is lacking competences in certification, general knowledge of DGNB system, availability of proper (digital) tools or resources to generate the required data are sparse (Møller et al., 2018). The digitalization in this industry is intertwined with the benefits of certification which is raised many times by all parties. We have paid a specific interest towards this problem: the intertwined of digitalization and certification. Generally, new technologies (especially information technologies) are often implemented with inertness as radical process changes in organization and work are required to gain the benefits, hence digital technologies represent often unforeseen risks and costs. Barriers to certification are described by the parties as lack of management mechanisms, economics, lack of demand and competence of customers, stress on organization and processes (procurement and supply, timing, collaboration and networking), and lack of supporting knowledge (knowledge and common language, availability of methods and tools, innovation) (Møller et al., 2018), (Häkkinen and Belloni, 2011).
As the industry is picking up on producing and procuring information about DGNB certification, it seems that the main barrier for engagement is the extensive bulk of documents and documentation procedures required to get a certificate. Silver, gold or platinum level certificates require extensive documentation of tests, calculations, simulations and decision processes. Traditionally, production of documentation is undertaken in relation to the physical construction process, but a DGNB certification will rely only upon assessment of documents and buildings performance. It introduces new challenges and demands upon organizations, understanding of fulfillment of tasks, on professional competences and collaborative skills (Worm, Amdi Schjødt et al., 2014). Successful certification requires transitions of and within the organization, and innovation in work methods and processes. Currant working regimes must be adapted to the new tasks and demands of DGNB certification by introducing new tasks (tests, simulations and calculations) the division of labor, decisions and responsibilities.

The paper analyses some factors in the certification process; i.e. where the DGNB system challenges organizations by demanding changes in documentation and work practices. By presenting experiences from involved actors, we can gain an insight into some of the core challenges and consequences that a DGNB certification can lead to. We hope that this can help to create appropriate, efficient, and systematic modes of work, to achieve the respective DGNB scores. The research main question: *What is the impact of Danish Green Building Certification (DGNB) on organizations work processes and documentation work?*

LITERATURE REVIEW

A study conducted by Herazo & Lizarralde, 2015 reveals that the processes within Sustainable/Green Buildings Certification (GBC) are shaped by at least four tensions that can either enhance or hinder the collaboration and innovation: strategic-tactical, collaborative-competitive, participativeeffective and individual-collective. They highlight the importance of understanding GBC as a process and not only as a final outcome, and thus, to better manage these tensions so they contribute to product and process performance (Herazo and Lizarralde, 2015). GBCs imply a process where actors meet to weigh their capacities to respond to new challenges. However, to attain GBCs, important management innovations must be conducted by the client at strategic, tactical and operational levels. In the same manner, design teams and contractors need to engage in innovative processes, systems, technologies, products and materials. The four tensions show that important changes were implemented at different levels after GBCs were identified as project objectives. The results of the study infer that the earlier the stakeholders participate in the process, the more efficient the process of collaboration becomes and the less risky it will be. GBC processes encourage client organizations to choose 'Integrated Design' procurement methods (Herazo and Lizarralde, 2015).

A study by Kovacic & Sreckovic, 2012 argued that a little effort has been invested into the rethinking of the design and planning process for sustainable buildings which are still planned in a traditional manner, where planning tasks are broken down into sequenced, highly specialized disciplines (Kovacic and Sreckovic, 2013). The authors stated that practitioners, when designing the planning process for sustainable buildings are aware of the need for a paradigm change in the planning culture and are asking for methods towards a more integrated, collaborative practice. Special emphasis lies on the need for developing soft tools for the design of interdisciplinary communication and knowledge management since the hard tools, e.g. LCA & LCC have been accepted in practice. The authors have identified the advantages of the integrated planning practice, by conducting a role-playing experiment simulating integrated and sequential planning processes for an energyefficient structure and identified the need for collaborative interaction between actors and development of a holistic life-cycle oriented planning strategy and mechanisms supporting the interdisciplinary communication, knowledge creation and transfer within the integrated planning processes. Critical herewith is the collaboration of all process stakeholders (planners, users, managers)

from the early planning phases, since those are crucial for the latter building performance. They concluded that all roles were more satisfied with Integrated Design Process (IDP) (Kovacic and Sreckovic, 2013).

The (IDP) method is applied in sustainable certification of buildings in Denmark, however it does not ensure aesthetic or sustainable solutions, especially in an early design phase, but it enables the designer to control many parameters that must be considered and integrated in the project when creating more holistic sustainable architecture in order to achieve better sustainable solutions, because all different parameters are considered during the process (Tine Ring, 2005). The main concern is the integration of the many different parameters, as this is considered the key to create more holistic sustainable architecture. The idea is that control and integration of so many different parameters in a project ensures a better interaction of systems and therefore also can raise the degree of sustainability. People involved in sustainable building design need to adapt to transdisciplinary teamwork which calls for new means of communicating (Tine Ring, 2005).

A case study conducted on four DGNB certificated health center's in Denmark highlighted the importance to collaborate in the design team from the beginning also with the DGNB consultant and create commitment to the project (Brunsgaard, 2015). Sharing knowledge will improve the decision making. The design team did not find difficulties in implementing DGNB-assessment in their work, however, responsibility and fee for the work is not clear. The quality of the process, and the final design of the building can be improved by a more conscious planning and management of the process (Brunsgaard, 2015).

Landgren & Jensen, 2017 (Landgren and Jensen, 2017) investigated how DGNB certification affect the design process in an architectural office in Denmark, concluded that Integrated energy design (IED) must be expanded to include a broader range of parameters in the DGNB certification process, fulfilling in this way a bigger number of DGNB criteria and consequently obtaining an easier process through design phase (Landgren and Jensen, 2017). The spread and variation in the DGNB related parameters addressed in the projects are symptomatic of the lack of a systematic design method for addressing DGNB. The design process is affected when certification systems are used, as new parameters must be in focus from the very early design phases. In the DGNB-system, LCA & LCC encourage adaption of holistic methods with a wider array of parameters and tools to quantify sustainability in terms of economic and environmental impacts. Both calculations include the energy consumption results generated by IED. Integrating LCA & LCC into the early design phases is a new challenge for practitioners and researchers, which requires further investigations. Landgren and Jensen recommended developing new methods and tools to increase the use of DGNB in the early certification process, it will be expected that this will lead to high complexity, due to the bigger number of parameters, but the rapid development of tools will be capable of dealing with that complexity (Landgren and Jensen, 2017).

A survey among Danish DGNB consultants (Brunsgaard, 2017), show that they are not involved early in the design process and they find it difficult to implement LCA & LCC early in the design phase. At the same time, LCA & LCC are well-documented in early phases and only partially implemented until the final stages (construction phase), questioning if the calculative models are really holistic and fit to produce adequate and solid foundation to choose among alternatives. Thus, potentials for optimizing sustainability, equivalated to the collected points in DGNB assessment can be missed, at the same time the choice of materials is highly linked to the architectural qualities, e.g. aesthetics and perception and buildings physical performance (Brunsgaard, 2017). The study shows a potential in developing new methods and tools to support the initial design phases facilitating an iterative decision making and design process based on sufficient level of knowledge and covering many topics (Brunsgaard, 2017).

All stages of a certification process should take into account the environmental considerations, unfortunately, practitioners encounter difficulties in case of brand new products due to the absence of environmental impacts feedback. To solve this problem, it is argued that the functional analysis of products (early stage in the design process) and LCA (late stage in the design process) can benefit each other in a collaborative process (Moreno et al., 2015). A critical literature review conducted by Anand & Amor, 2016 (Anand and Amor, 2017) highlights the gaps in LCA and consider it as one of the most complex applications in analyzing sustainable buildings due to the numerous materials and processes involved, especially in the operation phase compared to the construction phase. The construction phase inventory data for LCA of a whole building is highly dependable on LCA data of buildings components and materials, in addition to several challenges through the various phases of a building's LCA, e.g. the building design, stakeholder criteria, cost, environmental targets and user's. Building inventory data is obtained from building industry, databases or Environmental Product Declarations (EPD) which is directed by the Danish Technological Institute. The availability of product data for design phase in LCA of buildings seems to be a challenging issue for designers due to the absence of environmental feedback. There are various areas which requires industrial involvement and collaborations to promote the use of LCA by developing better databases to cover the gap of missing data for new and old products and to integrate LCA in buildings industry for environmentally conscious decision-making (Anand and Amor, 2017). Other challenges, is the uncertainty in data collection methods, thus Anand & Amor propose to develop a standard and ISO for better guidance (Anand and Amor, 2017).

The DGNB framework

The DGNB framework operates a hierarchy of criteria organized in six qualities, which unfolds the holistic framework assessing the overall sustainability of the building. They include the environmental, economic, social and technical qualities, which each present 22,5 % of the total score, while the process quality presents 10 % of the total score. The site quality is evaluated separately. According to the weighted qualities, the building will be granted (platinum, gold or silver) certification (DK-GBC, 2012). The required documentation includes; DGNB evaluation matrix, LCA and LCC calculations, EPD's, buildings description and built-up areas, installation

services, day light and indoor air climate simulations, energy calculations and energy concepts, water calculation, building site, etc. in addition to the documentation siding the certification process e.g. meeting references, contracts and organizational charts.
A life Cycle Assessment is a holistic approach to determine the total environmental impacts of a product or service from extraction of raw materials and processing, to distribution, use, and end of life. It is measured from a multitude environmental category, such as global warming, acidification, or human toxicity. In practice, LCA is intended to produce information to compare different alternatives in the design of products or decision-making processes (Birgisdóttir, 2015). The Danish States Building Institute (SBI) on behalf of the Danish Transport, Construction and Housing Authority have developed LCAbyg and LCCbyg tools to conduct the calculations (SBi, 2016). The LCA tool contains a catalog of a range of construction products based on generic data from the construction database Ökobau.dat (Kuhnhenne et al., 2010). At product level, Environmental Product Declarations (EPDs) is a method of documenting and declaring the sustainability of construction products and is based on Danish environmental declarations. DGNB uses the EPDs life cycle analysis to calculate the overall environmental impact of the building during its entire life cycle (DK-GBC, 2014). Economical quality requires that there is a balance between costs and achieved quality over the life of the building, and that there is focus on the value creation generated in construction and operational phases. Economical quality is ensured by applying the calculation of total economy for buildings construction, operation and maintenance expenses, through its entire life (SBi, 2016). Integrated Design Process (IDP) is a holistic method that intertwines knowledge elements from engineering with the design process of architecture to form a new comprehensive strategy to optimize building performance. This implies evaluation and weighting of very different building performance characteristics that are often non-comparable and requires willingness from all participants to reach acceptable compromises (Resources, 2007).

Analytical frame

We have applied a framework from (Orlikowski & Gash) (Orlikowski and Gash, 1994) and (Yrjo¨Engestrøm) (Engeström, 1987). Orlikowski has written extensively about organizations and technology, especially about ICT introductions in organizations. She has argued that users are less prone to 'appropriate' technologies as they are to 'enact' technologies to co-join the local practices. The continuous enactment of technologies can either confirm and reproduce prevailing organizational structures and cultures or can produce changes and transformation in the organization. Interviews were analyzed to detect and unfold challenging issues and barriers related to the work processes and work in a DGNB certification process. According to the analysis framework defined by Orlikowski & Gash (1994), the three domains that will cover what the technology is, why it was introduced and how they were used, are:

- **Nature of Technology** refers to people's images of the (generic) technology and their understanding of its capabilities and functionality, benefits and demands.

- **Technology Strategy** refers to people's understanding of the motivation behind the adoption and its likely value to the organization, in relation to actual plans assisting its implementation.
- **Technology in Use** refers to people's understanding of how the technology will be used on a day to day basis and the likely or actual condition and consequences associated with such use.

Here Orlikowski & Gash use opinion-making process in which actors develop expectations, knowledge and assumptions to technology. According to the analytical framework by Orlikowski & Gash, the three domains characterizing the enactments of the subjects acting to make practical use of the DGNB framework in their particular position in the construction project organization. The domains overlap and interacts but are useful for directing questions and interpreting answers. Our interview guide had organized questions along the following four domains:

- Documentation and process of work
- Organization and responsibilities
- Collaboration
- Tools and programs

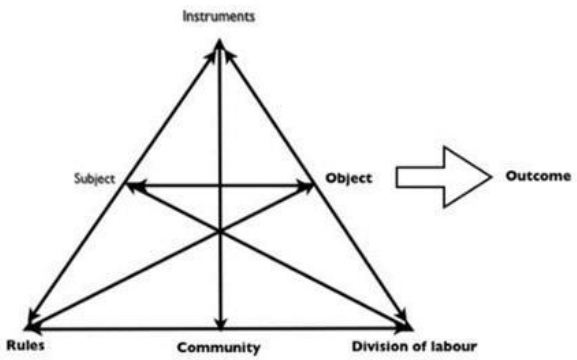

Figure 1The structure of human activity by Engeström, Y. [24] *1987*

The premise of Activity Theory (AT) as shown in figure 1, is that a collective work activity, with the basic purpose shared by others (community), is undertaken by people (subjects) who are motivated by a purpose or towards the solution of a problem (object), which is mediated by tools and/or signs (artefacts or instruments) used to achieve the goal (outcome). The activity is constrained by cultural factors including conventions (rules) and social organization (division of labor) within the immediate context and framed by broader social patterns (of production, consumption, distribution and exchange). AT provides a conceptual framework from which we can understand the inter-relationship between activities, actions, operations and artefacts, subjects' motives and goals, and aspects of the social, organizational and societal contexts within which these activities are framed.

RESEARCH METHOD

As we are conducting a single embedded case-study with multiple units (Yin. Robert K., 2014) to investigate changes and challenges of the work processes related to DGNB-certification, we have applied several research methods to gain information and qualify our findings (aka triangulation). The choice of case study design is due to sensitivity towards relational and contextual data and information from the respondents, as each respondent take different

positions and are referring to different construction projects. We have conducted literacy assessment as presented in Literature Review chapter and several semi-structured interviews (Kvale, 1996) conducted with selected respondents involved in (ongoing) DGNB certification processes.

Selection of respondents

Our project design aimed to produce information from multiple positions who took part in the process of certification in the organization, to capture the controversies and diverging assessments of the single movements undertaken in the certification process. We have made in-depth interviews with five respondents who are experienced professionals with profound knowledge and experience with DGNB certification system and have designed the interviews to gain insight into their experiences with practical processes in the organization. Our main project involves interviews with five respondents: one Architect, two Builders, one Contractor and a DGNB auditor. Two of the interviews constitute the backbones of this article, that are a DGNB Auditor (Au) and an Architect (Ar), which were rich in information required to investigate the challenges in a certification process.

Interview design and execution

We firstly made an interview guide, following the strategy for 'semi-structured interviews' (Kvale, 1996). A questionnaire and a mediating chart were sent to the respondents by mail a week before the interviews. The chart depicts the standard building phases and our idea was to stimulate the respondents to identify the DGNB documentation work related to each phase, and especially where they had experienced significant changes in working processes and challenges in production of documentation work (changes in organization). The charts served as a structuring common object during the interview and as an agent for producing insight into our investigation, questions and debate during the interviews. The interviews were recorded, then transcribed by UCN students.

RESEARCH FINDINGS

What is the Impact of Danish Green Building Certification (DGNB) on organizations, their work processes and documentation work?

In the analysis we are focusing upon the various sensemaking domains (Orlikowski and Gash, 1994), and the relations shaping outcome as framed in AT (Engeström, 1987). The informant's statements are organized so they respond to the analytical domains, and sketches the activities of the various subjects (informants):

Work demands and process of work

Au is employed as consultant and has participated in a number of DGNB certification before being a certified auditor, when he was asked to evaluate which phase is the most demanding in relation to documentation work, he stated: *"There are some elements that, in all conditions, must be done in the context of certification, sometimes it starts earlier than usual, it extends until the building construction is completed and continues 1-2 months in the operation phase too…the are several activities that require extra work and are distributed across all phases".*

Au pointed out that the documentation for DGNB certification work runs across all building phases and cannot be attributed to a specific phase. It can be produced in different times through the process, but the earlier it is, the better it will be to obtain higher quality of work. He highlights that during the long certification process, there are some activities, especially the LCA & LCC that require extra work and time (as they start early and continue in operation phase) and it's here where the biggest potential in optimizing the documentation in a certification process is essential.

Documentation work

Au clarified how the type of documentation produced in a traditional building deviate from a DGNB certificated one, he distinguished between Standard Documentation (SD) to comply with Danish Building Regulations (e.g. energy frame, indoor climate and accessibility regulations) and other documentation required for a DGNB certification and emphasizes that SD is typically prepared in each building phase and presents 95 % of the documentation work which is required in a DGNB certification. Au points to the role of DGNB in establishing an overview of the building's overall documentation. However, the DGNB system introduces several tools that are used to convert data (from the documentation) to obtain points for fulfilling criteria. It is in connection with the use of these tools where Au identifies that there can be 'more work'. According to Au's opinion, there is no doubt that LCA & LCC calculations require the biggest amount of documentation work in setting the quantities of materials, collecting and defining data. Both calculations weights about 23 % of the whole certification, so accordingly it is evident that many points can be gained here. In addition, there are also the water calculations and day light simulations, which are similarly considered as 'more work'. Au explains how the desired level of DGNB (platin, gold or silver) influences the nature of documentation work, as the higher the DGNB ambitious level is, the more work it requires to gain the highest scores. Thus, huge efforts must be made to fulfill the different criteria if the ambitious level is platin. He adds that in this way DGNB certification affects the entire organization and the knowledge gained in the different areas. However, Au clarifies that it is possible to start the certification process earlier if the Revit models are set correctly from the beginning, so it becomes easier to extract the right data and quantities. On the other hand, Ar admitted the production of new documents in DGNB projects in comparison with traditional ones. The new 'extra' documentation work is mostly produced in the programming phase, but it gets more extensive in the construction phase. It was declared that the certification process will be more time and resource consuming if the required certification level is Platin.

Au adds that the most important benefit by making a DGNB certification is that the documentation work, is a comprehensive collection of all documents and assumptions for all buildings data and materials, so it is easy to refer to these documents when the building is operated, and in case of maintenance and renovation, which saves a lot of time and efforts to find the right data of materials. By that, the builder will also have a well-documented building with all relevant documents, calculations, or meeting minutes, so one can refer to them and see what was really agreed in the meetings, if for example, any complains arises later by the buildings users. He provided an example of a certificated building, in operation phase, where occupants experienced overheating problems in meeting rooms, and by referring to early client meetings and indoor climate analysis, it was found that the rooms where designed for a max. of 6 persons and not 10!

Ar also points out that, regardless of whether more work is done or not, a DGNB certification only provides a higher quality of building, plus in relation to the sustainability aspects, the building will have a more flexible use, that it can be changed to another type of use in the future.

Collaboration strategy

In relation to the collaboration between Au and the other involved actors, Au clarifies some new work strategies that will influence the documentation work:

"The way we <u>always</u> start up a DGNB project, is by having a workshop where we review the various stakeholder's responsibilities to know what must be provided and required, just to get into this with the fact that you have to deliver something early in relation to areas (gross, net and utility areas)".

Here, Au highlights the importance of the actors understanding of their responsibilities and work tasks, when starting a DGNB project. He provides an example, that one of the first important steps is to set up Revit models correctly from the beginning, so all areas will be calculated automatically, and by that avoiding a bulky process. In addition, Au mentions that the way that engineers and architects work with each other is different in a DGNB project, and from his point of view, the DGNB certification is beneficial for an efficient work process. As when starting a DGNB certification, some documents and data are required early in the process and by that DGNB locks the projects in some areas, preventing to make many design changes. In many cases he experiences that architects have other interests than engineers, where they like to consume more time in the design. Au clarifies:

"*The process now is locked, as we all know that we have the areas defined from the beginning and if you move something in Revit, then other things will be influenced, so it's been revealed*

to all that it has a consequence, while before it was just a silly mail from the engineer that they should stop moving the door, because now we have 4 men sitting there and are moving outlets".

In comparison, Ar is aware of the importance of acting in a flexible way together with the rest of team members (total contractor and engineer) and must be open to any decisions without influencing fulfilment of DGNB criteria's. For example, many criteria are linked to each other, and a single modification in the DGNB matrix will influence other criteria. This requires documentation of these criteria which influence each other before proceeding the rest of the documentation work. Ar mentions that they have most often participated in DGNB projects that have been offered in competitions, so there have been naturally several meetings in the competition team. She mentions that it is vitally important that all facets are present before voting and that the team make a preagreement on the desired DGNB level, before the crosses are marked on the DGNB matrix. On the other hand, she confirmed that working with a DGNB project adds a great advantage to the work processes as it will bring all actors in a close relation, with a common and determined aim to achieve the required level of DGNB:

"When working with DGNB, you will have a very close collaboration with others, if the aim is the platin certification, then all actors must work towards the same target, willing for the good process, so if you want to change something, then you need to think about the consequences, what does it matter to price, materials, etc. Otherwise you'll have to go through the whole process again".

In addition to above, Ar declares that DGNB system today have contributed to architectural firms, by directing their attention to the design phase and considering the points that they have not addressed previously. Ar mentions that despite the architecting company has a green profile and they have probably been aware of material choices, but the difference today is that they must consider other parameters in the matrix too.

On the other hand, Au confirmed that working in an IDP will bring the right skills and disciplines into play along the whole process. Similarly, Ar admits the importance of IDP and how it's part of their team 'DNA' and work traditions in all projects and that the buildings complexity requires that all facets should be involved very early in the certification process with a common goal and ambitious intentions to achieve the certification in an efficient way.

Document management strategy

When Au was asked if they use any document management system or a certain platform to collect the documents, he clarified that he has his own folder structure, where all documents are gathered in relation to the individual qualities. In addition, he has self-developed, a responsibility and delivery matrix where he has set up who is responsible for what and who

are the producers. He also further processed the changes that have been in DGNB manuals. On the other hand, they are aware that some new tools have been started to be used, but they haven't used any of them yet.
Au adds that according to DGNB, there is still so much analogue in relation to documentation as there is no sort of system where you can have for example access to the client meeting-minutes, or any required documentation. It is important that documents are transparent to all involved actors. Having a common document management tool is essential to retain the process running effectively and to involve all actors in all phases. It will make it easier to refer to any document at any time, specially that it's a long process and it might be difficult to remember what was done earlier. Thus, it will consequently serve as a quality assurance tool for all documents. In addition, he proposed digital delivery of the documents to Dk-GBC, which will save resources. Ar mentions that they have self-developed their own spreadsheet in Excel to control the documents, which is a user friendly and easy tool. They have listed the criteria, so they can gain an overview of what they began, what is missing, which documentation is delivered and when it must be delivered. However, Ar requests for some guidelines or common templates form, for example, DK-GBC or other organizations, so they can be downloaded and re-used in all projects. Further developments as recommended by Ar, could be done by linking the DGNB matrix to the excel files or calculations, so the results will be automatically adjusted in case of any changes.

Technology in use

As mentioned previously by Au, the biggest resources are without doubt related to the LCA & LCC calculations, as there are numerous quantities of materials and data to be collected and processed in LCA & LCC tools. He also addressed the extra efforts to lack of materials data and EPD, which makes it difficult to define in the LCA tool and can create some obstacles, which requires extra efforts to find the most suitable material: *"The biggest challenge is (if you can) in the LCA analysis document the materials. Right now, it's build on some databases and you can add your own materials, but then you must have some declarations of the components, what they include, the primary energy and everything related to the material".*

Furthermore, Au mentioned that when they first started working with DGNB certification at the beginning of 2013, there was almost no EPD's available. Today, more EPD's are provided by producers and the Danish organization (EPDDanmark) ('EPD Danmark', 2018). He adds that it will be beneficial if producers support their products by providing data for a wide range of products and not only traditional ones.

Au adds: *"The problem is probably more than it's a fairly heavy process of collecting data, as one must be right in the long run of the project to be able to estimate some <u>reasonable</u> amounts".*

The problem from Au's point of view is not only about considering the environmental impact of the materials, but also estimating reasonable quantities and ensuring that the various decisions make sense by analyzing and following-up the consequences related to other aspects e.g. the total cost calculations, energy aspects, fire and sound requirements, loadbearing of the structure, methods of construction, etc. On the other hand, Ar confirms that the extra efforts related to DGNB today, will pay back in the future with less efforts, high qualified process and new experiences and knowledge.

DISCUSSION

It is evident from the empirical analysis that the certification process requires extra efforts and time, as many activities start earlier than usual, they continue along all building phases and extend in the building's operation phase. Similar, research work by Herazo & Lizarralde mention that it is essential to start up the process early (Herazo and Lizarralde, 2015), they agree that the earlier the sustainable projects are started, the more efficient and less risky they will be. Results from interviews show that the documentation work related to LCA & LCC are one of the extensive ones, due to the huge quantity of collected data, that start early in the design phase, then become more extensive in the construction phase. A survey by Brunsgaard & Bejder mention that documentation work related to LCA & LCC is mostly conducted in design and construction phases, meaning that they don't have a holistic nature through the whole process (Brunsgaard, 2017). However, they mention that it is difficult to integrate LCA & LCC into early design phases. Similarly, Landgren and Jensen mention that it is a new challenge for practitioners (Landgren and Jensen, 2017). Our results agree with the reviewed studies (Landgren and Jensen, 2017), (Brunsgaard, 2017) to develop new methods/ tools to support the initial design phases. It can be by simplifying the use of LCA & LCC tools or by implementing Revit to them, so material quantities will be extracted from Revit and exported to them. Both, our research findings and a study by Anand & Amor (Anand and Amor, 2017) agree that lack of materials data and their EPDs, obstructs the certification process. Producers must make a jump in their profession and provide data of their materials, so documentation work will be reduced and improved.

DGNB brings all involved actors in a close collaboration. Both interviewers confirmed that they usually work in an integrated design process and highlighted the benefits of it and their determination to collaborate early in the process, which is very essential when working with DGNB projects. Similarly, Kovacic & Sreckovic confirmed that actors are aware of the need for collaborative interaction, supporting the interdisciplinary communication and knowledge management between them (Kovacic and Sreckovic, 2013). Brunsgaard highlighted the importance to collaborate in the design team early and concluded that quality of the process, and the final design of buildings can be improved by a more conscious planning and management of the process (Brunsgaard, 2015). Our analysis confirms the awareness of different actors in taking decisions, as the wide spread of parameters and DGNB criteria force them to act differently by not making many design changes and to be aware of the consequences in taking decisions and ensuring that they make sense by analyzing them in relation to other aspects, as many criteria are linked to each other. However, Landgreen &

Jensen found that the spread and variation in the DGNB related parameters addressed in the projects are symptomatic of the lack of a systematic design method for addressing DGNB. The design process is affected when certification systems are used, as new parameters must be in focus from the very early design phases (Landgren and Jensen, 2017). According to our findings, it is recommended to develop common guidelines to support the complexity of wide range of criteria and parameters, especially in the design phase.

It is found that organizations today develop their own document management systems. Our findings and reviewed literature emphasized the importance of simplifying and qualifying the certification process and documentation work by digitalizing it. This can be by developing common document management tools accessed by all users, so all documents will be saved in one platform with a clear definition of actor's tasks and their activities, supporting the interdisciplinary communication. However, at the end of the process, DGNB serves as a comprehensive way to document buildings. The authors would like to thank Northern Jutland Region, Aalborg Municipality, COWI A/S Consultants, Lund & Staun A/S Contracting and Bjerg Architects for their cooperation.

CONCLUSION

This study provides an insight in how DGNB certification influences working processes and documentation work in organizations. It provides awareness of the issues that need to be addressed and suggests solutions to facilitate DGNB certification. It is concluded that an increased interdisciplinary interaction between involved actors in an early phase is necessary to tackle the increased complexity of sustainable building process. Actors work in a more goal-oriented way to achieve the required level of DGNB. They are also aware of the nature of DGNB criteria which prohibits changing many deign parameters and have influenced the actor's way of behavior by making them understand the consequences of any decision changes. Activities, specially LCA & LCC calculations, requires extensive efforts through the whole certification process. Lack of data for buildings materials is also an obstruction in conducting the LCA. Actors request digitalizing documentation work processes by developing common skillful tools for efficient management of documents accessed by all involved actors to facilitate the collaboration between them, increase work efficiency and ease off documentation management with a clear definition of the actor's responsibilities. Benefits associated with DGNB certification include a well-documented and qualified building, directing the attention of practitioners to many important parameters that were not considered before. According to the research findings, we recommend the following:

- A discussion to facilitate the certification process by having a common digital platform accessed by all users to manage all documents, allowing effective communication between them.
- Developing utilities to simplify the use of LCA & LCC tools, a solution can be by making Revit compatible to them, enabling data extraction from Revit into these tools. Further research can be made to investigate the challenges and possible solutions related to these tools.

- Producers must facilitate the process by providing a wide range of materials data and EPDs.
- Linking DGNB matrix to the various calculations to avoid extra efforts when adjusting any criteria. - Providing instructions to support decision makers when working with DGNB matrix and criteria.
- Using common documents or calculation templates, provided by DK-GBC, to ensure the quality of the documentation and to enable using them in other projects.

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DISPLAY ENERGY CERTIFICATE AND ADVISORY REPORT LOCAL GOVERNMENT COMPLIANCE IN NORTHERN ENGLAND

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Abstract

This paper is part of a Doctor of Engineering (D.Eng.) research that is investigating Central and Local Government Compliance with Display Energy Certificates (DECs) and Advisory Reports (ARs) in England and Wales. In this paper, summary statistics are produced on DEC and AR ratings, lodgement, and 'Fabric-First' priority recommendations of Local Governments Authorities (LGAs) in Northern England for 2008 to 2017. Northern England is England's North East, North West and Yorkshire and the Humber. This is the first independent synthesis of data of this kind, which provides evidence on DEC and AR Local Government compliance in Northern England. This paper adopted and adapted research guidance for development of its Protocol for Quantitative Analysis of Local Government DEC and AR Compliance. It involved:

- *Accessing the OpenDataCommunities Platform to retrieve and catalogue DEC and AR bulk data for all LGAs in England and Wales.*
- *Undertaking data cleaning to verify the integrity of the DEC and AR bulk data and to detect unintentional data corruption and duplication.*
- *Undertaking Content, Statistical and Comparative Analyses to determine the extent of DEC and AR poor-ratings, non-lodgement, and 'Fabric-First' priority recommendations for LGAs in Northern England.*

The significant findings from this study include that: 7.2% of the 375 LGAs in England and Wales appear not to have lodged DECs and ARs via the OpenDataCommunities Platform; While none of the 22 LGAs in Wales have DEC and AR non-lodgement, 27 of the 353 LGAs in England have DEC and AR non-lodgement; The majority of DECs for the North East, North West, and Yorkshire and Humber regions of Northern England were rated 'D' with about 36.782%, 38.228%, and 34.856% respectively; The percentage of total DECs for these regions that will likely not meet the Government Property Unit target to attain DEC 'A' to 'D' ratings by 2018 are 32.228%, 36.077%, and 38.105% respectively; and The percentage of total AR Priority Recommendations for these regions that are related to the 'Fabric-First' approach are about 7.704%, 10.212%, and 8.458% respectively. These are significant, as it underlines likely difficulties that may be faced should minimum energy performance standards be introduced at a future date. The implication of such difficulties with compliance at this regional level is that the DEC and AR are not yet being fully complied with (or enforced) as originally intended by the principle underlying the Energy Performance of Buildings Directive (EPBD). Future work will include: synthesis of quantitative evidence on DEC and AR LGA compliance in Wales and other regions of England; and creation of a Protocol for Qualitative Analysis of UK Government DEC and AR Compliance. These will help determine why DEC and AR poor-ratings, non-lodgement, and 'Fabric-First' priority recommendations occur for UK Central Government and LGAs in England and Wales.

INTRODUCTION

The Problem Statement

This paper's authors have a keen interest in Energy Certification Compliance, which they have investigated and disseminated via publications such as "Do Display Energy Certificates (DECs) Work?" and "Setting an Example" in Osaji *et al.* (2017a and 2017b). The DEC was introduced by the UK Government in order to track energy consumption and in response to the European Union (EU) Energy Performance of Buildings Directive (EPBD) (DCLG, 2014). The UK Government transposed the DEC into regulations in 2007, with legislation requiring DECs: to be displayed prominently by public authority buildings greater than 250m^2 in total useful floor area; and accompanied by Advisory Reports (ARs) that provide recommendations on potential energy saving measures (DCLG, 2016).

However, concerns have been raised by Bruhns *et al.* (2011) and Hong and Steadman (2013) because of a 20% and over-50% non-compliance with the DEC scheme respectively. In 2017, this paper's authors investigated and disseminated summary statistics on DEC and AR ratings, lodgement, and priority recommendations of UK Central Government buildings for 2008 to 2017. Osaji *et al.* (2017a and 2017b) was the first independent synthesis of such data. It identified that DECs and ARs should be available for 510 UK Central Government buildings, but only 104 could be retrieved via the Non-Domestic Energy Performance Certificate (NDEPC) Register. This significant discovery implies an 80% non-compliance with the DEC and AR scheme by UK Central Government. It also discovered that the level of AR 'Fabric-First' priority recommendations for UK Central Government was apparently low. This occurred despite the endorsement of the 'Fabric-First' approach to energy efficiency by experts such as Leeds Sustainability Institute and Building Research Establishment, as described in Johnston (2015) and Stenlund (2016) respectively. The implication of such non-compliance is that the DEC and AR are not yet being fully complied with (or enforced) as originally intended by the principle underlying the EPBD. In light of such non-compliance, and European Parliament's 2018 revised EPBD approval, this paper's authors will investigate DEC and AR Local Government compliance, starting with Northern England. This area covers England's North East, North West, and Yorkshire and the Humber, as described in IPPR North and NEFC (2012).

The Aim

This paper's aim is to determine the comparative levels of DEC and AR compliance of Local Government Authorities in Northern England for 2008 to 2017.

The Objective

This paper's objective is to determine how widespread the issues of DEC poor-ratings, DEC and AR non-lodgement, and AR 'Fabric-First' priority recommendations are for Local Government Authorities in Northern England.

THE METHODOLOGY AND METHODS

A Protocol for the Quantitative Analysis of Local Government DEC and AR Compliance was developed and used by this paper to fulfil its aim and objective.

Protocol for the Quantitative Analysis of Local Government Dec and AR Compliance

In Fylan (2017; and 2018), Glew (2017), UCEM (2017), and Wu and Amoo (2018), Research Guidance is provided on aspects such as: Research Design; Statistics; Qualitative and Quantitative Research Methods; Effective Research Project Management; and Mixed Methods Research. In Ministry of Housing, Communities and Local Government (2018), Data on the Energy Performance of Buildings in England and Wales is provided via the OpenDataCommunities Platform.

This paper has adopted the Research Guidance, and adapted it to the Data on the Energy Performance of Buildings in England and Wales. This has resulted in the development of a Protocol for Quantitative Analysis of Local Government DEC and AR Compliance. This Protocol, which has been developed to fulfil this paper's aim and objective, is nonexperimental, and is described below:

Prepare searches of DECs and ARs in England and Wales:

- To summarise and incorporate key aspects
- To update assumptions

Address questions on DEC and AR Local Government levels of compliance for 2008 to 2017:

- What numbers of LGAs in England and Wales have fulfilled DEC and AR lodgement?
- What are the comparative levels of DEC 'A' to 'G' ratings for Northern England LGAs?
- What are the comparative levels of AR 'Fabric-First' priority recommendations for Local Government Authorities in Northern England?

Access information sources for Local Government DEC and AR data search and retrieval:

- Access the OpenDataCommunities Platform in order to retrieve and catalogue DEC and AR bulk data for all Local Government Authorities (LGAs). This is a total of 353 LGAs in England and 22 LGAs in Wales, according to Sandford (2018).
- Derive the locations of the 353 LGAs in England based on information by Ministry of Housing, Communities and Local Government (2016). The location information pertains to the following nine regions of England LGAs: North East's 13 LGAs (JSHAO, 2018d); North West's 40 LGAs (JSHAO, 2018e); Yorkshire and the Humber's 23 LGAs (JSHAO, 2018j); East Midlands' LGAs (JSHAO, 2018b); West Midlands' LGAs (JSHAO, 2018h); East of England's LGAs (JSHAO, 2018c); South East's LGAs (JSHAO, 2018f); South West's LGAs (JSHAO, 2018g); and London's LGAs (JSHAO, 2018a).

- Derive the location of the 22 Local Government Authorities in Wales based on information by Welsh Local Government Association (2018) and JSHAO (2018i).
- Use the derived location details to retrieve and catalogue available DEC and AR bulk data from the OpenDataCommunities Platform. These are supposed to be for the 353 LGAs in England, and the 22 LGAs in Wales, that is, 375 LGAs in England and Wales.

Verify DEC and AR data integrity by developing and using a data cleaning subprotocol:

- Develop a data cleaning subprotocol to verify the integrity of the DEC and AR bulk data and to detect unintentional data corruption and duplication.
- Apply four checks to the available DEC and AR bulk data as described below, according to A. Hardy, Research Fellow, Leeds Sustainability Institute (personal discussion on the DEC and AR data cleaning subprotocol, 5 March 2018).
- Apply the four checks to detect: (1) Entries that are exactly the same; (2) Entries that are the same, but with different lodgement dates; (3) Entries that are the same, but with different inspection and lodgement dates, that is, exactly the same DEC on a new inspection, which suggests a new inspection was actually not done; and (4) Entries where the inspection date is the same, but all other values differ (these may be genuine certificates, for which the assessor forgot to update the inspection date).
- Hash all relevant variables together by using a hash function in order to perform the data checks. For instance, the hash function is only to be applied to the inspection date in order to check for entries that have the same inspection date.
- Ignore variables that are not relevant to the DECs and ARs.
- Compare hash functions in order to search for duplicate hashes.
- Confirm that no duplicate errors have been detected in the DEC and AR database.

Conduct empirical research by using primary and secondary sources of data:

- Conduct empirical research by using primary sources such as historical documents and actual energy use data that have not been interpreted by intermediaries.
- Use primary sources for empirical research to derive, analyse, and generate data.
- Conduct empirical research by using secondary sources such as the DECs and ARs that contain the energy assessment and energy saving recommendations of intermediaries. However, use the secondary sources to derive, analyse, and generate primary data.
- Conduct empirical research by using the secondary sources for a critical analysis of the way the secondary data have been derived, analysed, and used to generate findings.

Conduct quantitative data analysis:

- Conduct Content and Statistical Analysis of the DEC and AR bulk data to quantify how many Local Government Authorities in England and Wales have lodged DECs and ARs.
- Conduct Content Analysis of the DEC ratings for Northern England Local Government Authorities by copying them from Excel to Microsoft Word documents.
- Conduct Statistical Analysis of the DEC ratings by using the 'Find' function in Microsoft Word to search for and determine the quantity and frequency of DEC 'A' to 'G' ratings.

- Conduct Comparative Analysis to determine the comparative levels of DEC 'A' to 'G' ratings for Local Government Authorities in Northern England.
- Conduct Content Analysis of AR priority recommendations for Northern England Local Government Authorities by copying them from Excel to Microsoft Word documents.
- Conduct Statistical Analysis of the AR priority recommendations by using the 'Find' function in Microsoft Word to search for and determine the frequency of 'Fabric'.
- Conduct Comparative Analysis to determine the comparative levels of AR 'Fabric-First' priority recommendations for Local Government Authorities in Northern England.

RESULTS AND DISCUSSION

DEC and AR Lodgement Summary Statistics for LGAs in England and Wales

There were found to be 353 Local Government Authorities (LGAs) in England and 22 LGAs in Wales, as described in Sandford (2018). Therefore, these 375 LGAs in England and Wales are expected to comply with the DEC and AR scheme, which DCLG (2014) state was transposed into regulations by the UK Government in 2007 in response to the EPBD.

However, although 375 LGAs in England and Wales are expected to comply with the DEC and AR scheme, this paper discovered that only 348 LGAs have lodged DECs and ARs that could be retrieved via the OpenDataCommunities Platform.

This implies that 7.2% of the 375 LGAs in England and Wales appear not to have lodged DECs and ARs via the OpenDataCommunities Platform, as shown in Table 1. This is a significant discovery, although it is in line with previous findings in Bruhns *et al.* (2011), Hong and Steadman (2013), and Osaji *et al.* (2017a and 2017b). It is not known if this was a data management issue associated with the bulk data set or if building owners in the LGAs had not undertaken the DEC and AR process.

However, the implication of such non-lodgement is that the DEC and AR are not yet being fully complied with (or enforced) as originally intended by the principle underlying the EPBD. Therefore, this phenomenon requires further investigation to understand why this may be the case. Table 1 also illustrates the DEC and AR Lodgement Summary Statistics for LGAs in England and Wales. It shows that while all 22 LGAs in Wales have DEC and AR lodgement, only 326 of the 353 LGAs in England have DEC and AR lodgement.

This implies that while none of the 22 LGAs in Wales have DEC and AR non-lodgement, 27 of the 353 LGAs in England have DEC and AR non-lodgement, which is 7.2% of the total 375 LGAs in England and Wales, as shown in Table 1.

Table 1: DEC and AR Lodgement Summary Statistics for LGAs in England and Wales

	Description	England	Wales	Total
1	Number of Local Government Authorities (LGAs)	353	22	375
2.1	Number of Total LGAs that have DEC & AR Lodgement	326	22	348
2.2	**% Level of Total LGAs that have DEC & AR Lodgement**	**86.933%**	**5.867%**	**92.8%**
3.1	Number of Total LGAs that have DEC & AR Non-Lodgement	27	0	27
3.2	**% Level of Total LGAs that have DEC & AR Non-Lodgement**	**7.2%**	**0%**	**7.2%**

DEC Ratings and AR 'Fabric-First' Priority Recommendations for North East England LGAs

Table 2 illustrates the summary statistics obtained from the DEC Ratings and AR 'FabricFirst' Priority Recommendations for North East England LGAs. As can be seen from Table 2, there is a spread of performance, but it is notable that the least percentages of the total DECs were rated 'A', 'G', 'B', and 'F' with about 0.843 %, 4.751 %, 6.195 % and 7.109 % respectively. The second and third most percentages of the total DECs were rated 'C' and 'E' with about 23.953 % and 20.368 % respectively. The majority of DECs for each of the 13 North East England LGAs were rated 'D' with about 36.782 % of the total DECs rated 'D'.

Government Property Unit (2013) has a target for buildings to attain DEC 'A' to 'D' ratings by 2018. Osaji *et al.* (2017a) showed that about 58% of UK Central Government buildings with available data will not meet this target. Table 2 shows that 32.228 % of the total DECs rated 'E', 'F' and 'G' for North East England will also not meet this target.

In regards the 'Fabric-First' approach to energy efficiency, Table 2 shows that 7.704 % of total AR Priority Recommendations for North East England were related to it. This approach has been endorsed by experts such as Leeds Sustainability Institute and Building Research Establishment, as described in Johnston (2015) and Stenlund (2016) respectively.

Table 2: DEC Ratings and AR 'Fabric-1st' Priority Recommendations (PRs) for North East England LGAs

		DEC 'A' to 'G' Ratings							Total DECs	Fabric - 1st PRs	Total AR PRs
		A	**B**	**C**	**D**	**E**	**F**	**G**			
No.	**North East England LGAs**										
1	Allerdale Borough Council	2	24	90	**109**	40	12	7	284	7	58
2	Darlington Borough Council	3	19	75	**145**	89	26	20	377	6	90
3	Durham County Council	12	115	419	**568**	292	118	100	1,624	12	208
4	Gateshead Metropolitan Borough Council	6	26	118	**288**	155	54	33	680	51	488

5	Hartlepool Borough Council	1	23	86	**122**	51	25	3	311	32	300
6	Middlesbrough Council	27	84	267	**289**	105	34	34	840	7	57
7	Newcastle upon Tyne City Council	14	137	393	**522**	303	124	117	1,610	94	1,651
8	North Tyneside Council	6	55	245	**283**	123	21	23	756	12	136
9	Northumberland County Council	14	89	346	**490**	377	138	59	1,513	20	551
10	Redcar and Cleveland	2	20	104	**353**	154	20	14	667	44	412
11	South Tyneside Council	1	22	103	**141**	119	69	20	475	25	221
12	Stockton-on-Tees Borough Council	2	33	234	**336**	161	27	19	812	7	92
13	Sunderland City Council	4	44	192	**457**	303	125	81	1,206	48	474
	Total	94	691	2,672	**4,103**	2,272	793	530	**11,155**	365	4,738
% of Total DECs Rated 'A'		≈ 0.843 %									
	% of Total DECs Rated 'B'	≈ 6.195 %									
% of Total DECs Rated 'C'		≈ 23.953 %									
% of Total DECs Rated 'D'		≈ 36.782 %									
% of Total DECs Rated 'E'		≈ 20.368 %									
% of Total DECs Rated 'F'		≈ 7.109 %									
% of Total DECs Rated 'G'		≈ 4.751 %									
% of Total PRs w/ 'Fabric-1st'		≈ 7.704 %									

DEC Ratings and AR 'Fabric-First' Priority Recommendations for North West England LGAs

Table 3 illustrates the summary statistics obtained from the DEC Ratings and AR 'FabricFirst' Priority Recommendations for North West England LGAs. As can be seen from Table 3, there is a spread of performance. However, it is notable that the least percentages of the total DECs were rated 'A', 'G', 'B', and 'F', just like those of the North East England LGAs, but with about 0.615 %, 4.589 %, 5.416 %, and 7.654 % respectively. The second and third most percentages of the total DECs were rated 'E' and 'C' with about 23.834 % and 19.671 % respectively. The majority of DECs for 37 of the 40 North West England LGAs were rated 'D' with about 38.228 % of these total DECs rated 'D'. The exceptions were Rossendale Borough Council whose majority of DECs were rated 'E' while Cumbria County Council and Lancashire County Council appear not to have lodged DECs and ARs.

In regards the Government Property Unit (2013) target for buildings to attain DEC 'A' to 'D' ratings by 2018, Table 3 shows that 36.077 % of the total DECs rated 'E', 'F' and 'G' for North West England will also not meet this target.

In regards the 'Fabric-First' approach to energy efficiency, Table 3 shows that 10.212 % of total AR Priority Recommendations for North West England were related to it.

Table 3: DEC Ratings and AR 'Fabric-1st' Priority Recommendations (PRs) for North West England LGAs

		DEC 'A' to 'G' Ratings							Total DECs	Fabric -1st PRs	Total AR PRs
		A	B	C	D	E	F	G			
No.	**North West England LGAs**										
1	Barrow-in-Furness Borough Council	6	16	72	**77**	33	8	2	214	6	67
2	Blackburn with Darwen Borough Council	6	58	110	**199**	181	90	45	689	8	71
3	Blackpool Council	0	23	195	**245**	61	23	12	559	2	106
4	Bolton Metropolitan Borough Council	3	14	159	**401**	358	112	87	1,134	39	378
5	Burnley Borough Council	7	27	79	**146**	108	23	8	398	7	47
6	Bury Metropolitan Borough Council	3	50	187	**367**	215	77	47	946	21	172
7	Carlisle City Council	1	34	88	**122**	72	49	16	382	12	90
8	Cheshire East	10	85	252	**615**	311	90	54	1,417	18	208
9	Cheshire West & Chester Council	23	54	284	**701**	338	89	47	1,536	44	487
10	Chorley Borough Council	1	10	56	**148**	142	56	15	428	3	52
11	Copeland Borough Council	10	14	51	**62**	37	13	13	200	6	40
12	**Cumbria County Council**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
13	Eden District Council	1	7	25	**55**	26	13	1	128	6	56
14	Fylde Borough Council	0	3	59	**133**	71	18	11	295	7	61
15	Halton Borough Council	0	11	60	**230**	119	27	14	461	11	126
16	Hyndburn Borough Council	6	24	54	**112**	103	42	21	362	3	17
17	Knowsley Metropolitan Borough	1	13	105	**309**	121	29	8	586	5	98
18	**Lancashire County Council**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
19	Lancaster City Council	3	69	192	**332**	202	58	18	874	8	76
20	Liverpool City Council	29	234	559	**860**	600	227	135	2,644	59	947
21	Manchester City Council	20	190	516	**644**	541	264	219	2,393	89	680
22	Oldham Metropolitan Borough Council	2	19	134	**327**	262	93	72	909	13	117
23	Pendle Borough Council	0	12	46	**135**	90	20	7	310	4	21
24	Preston City Council	4	42	249	**363**	217	72	63	1,010	15	117
25	Ribble Valley Borough Council	2	12	31	**95**	82	27	5	254	3	39
26	Rochdale Metropolitan Borough Council	6	36	150	**259**	224	102	55	832	16	101
27	Rossendale Borough Council	1	17	33	76	**104**	39	7	277	2	13
28	Salford City Council	4	57	204	**436**	291	74	24	1,090	19	178

29	Sefton Metropolitan Borough Council	4	82	353	**478**	302	105	67	1,390	9	165
30	South Lakeland District Council	6	19	80	**99**	41	16	8	269	7	99
31	South Ribble Borough Council	3	19	84	**236**	107	26	22	497	16	110
32	St Helens Borough Council	2	24	143	**326**	115	18	26	654	9	123
33	Stockport Metropolitan Borough Council	0	42	147	**430**	257	42	33	951	36	323
34	Tameside Metropolitan Borough Council	0	19	79	**236**	138	54	21	547	79	667
35	Trafford Council	0	20	100	**279**	170	50	22	641	33	355
36	Warrington Borough Council	3	31	164	**446**	214	74	52	984	57	437
37	West Lancashire Borough Council	6	74	125	**228**	162	26	28	649	8	74
38	Wigan Council	1	75	187	**486**	415	58	49	1,271	65	562
39	Wirral Metropolitan Borough Council	4	51	281	**424**	141	47	17	965	19	181
40	Wyre Borough Council	4	17	133	**205**	88	16	8	471	11	128
	Total	182	1,604	5,826	**11,322**	7,059	2,267	1,359	**29,617**	775	7,589
	% of Total DECs Rated 'A'										
	% of Total DECs Rated 'B'					≈ 0.615 %					
						≈ 5.416 %					
						≈ 19.671 %					
						≈ 38.228 %					
	% of Total DECs Rated 'C'										
	% of Total DECs Rated 'D'										
	% of Total DECs Rated 'E'										
	% of Total DECs Rated 'F'					≈ 23.834 %					
						≈ 7.654 %					
						≈ 4.589 %					
						≈ 10.212 %					
	% of Total DECs Rated 'G'										
	% of Total PRs w/ 'Fabric-1st'										

DEC Ratings and AR 'Fabric-1st' Priority Recommendations for Yorkshire and Humber LGAs

Table 4 illustrates the summary statistics obtained from the DEC Ratings and AR 'FabricFirst' Priority Recommendations for Yorkshire and the Humber LGAs. As can be seen from Table 4, there is a spread of performance. However, it is notable that the least percentages of the total DECs were rated 'A', 'G', 'B', and 'F', just like those of the North East and North West England LGAs, but with about 0.750 %, 5.923 %, 6.126 %, and 8.659 % respectively. The second and third most percentages of the total DECs were rated 'E' and 'C', just like those of the North West LGAs, but with about 23.523 % and 20.164 % respectively. The majority of DECs for 22 of the

23 Yorkshire and the Humber LGAs were rated 'D' with about 34.856 % of these total DECs for this region rated 'D'. The exception was North Yorkshire County Council that appears not to have lodged DECs and ARs.

In regards the Government Property Unit (2013) target for buildings to attain DEC 'A' to 'D' ratings by 2018, Table 4 shows that 38.105 % of the total DECs rated 'E', 'F' and 'G' for Yorkshire and the Humber will also not meet this target.

In regards the 'Fabric-First' approach to energy efficiency, Table 4 shows that 8.458 % of total AR Priority Recommendations for Yorkshire and the Humber were related to it.

Table 4: DEC Ratings and AR 'Fabric-1st' Priority Recommendations (PRs) for Yorkshire and the Humber LGAs

		DEC 'A' to 'G' Ratings							Total DECs	Fabric - 1st PRs	Total AR PRs
		A	B	C	D	E	F	G			
No.	**Yorkshire & Humber LGAs**										
1	Barnsley Borough Council	0	21	95	**180**	162	76	7	541	3	64
2	Bradford Metropolitan Council	13	129	306	**495**	439	168	68	1,618	21	166
3	Calderdale Metropolitan Borough Council	16	61	115	**319**	271	103	64	949	31	464
4	City of Wakefield Metropolitan District Council	14	67	201	**382**	297	124	119	1,204	75	1,003
5	City of York Council	6	124	245	**266**	169	48	30	888	28	373
6	Craven Borough Council	2	29	53	**119**	72	11	7	293	39	652
7	Doncaster Metropolitan Borough Council	5	96	274	**554**	392	162	117	1,600	35	347
8	East Riding Of Yorkshire Council	8	59	244	**443**	393	186	76	1,409	67	634
9	Hambleton District Council	0	8	89	**134**	102	20	16	369	66	974
10	Harrogate Borough Council	17	54	134	**274**	159	30	17	685	110	1,444
11	Hull City Council	4	82	327	**617**	356	111	53	1,550	34	421
12	Kirklees Metropolitan Borough Council	13	112	375	**703**	279	77	43	1,602	141	1,360
13	Leeds City Council	21	142	539	**853**	720	313	333	2,921	186	2,090
14	North East Lincolnshire Council	1	40	239	**280**	135	32	18	745	11	85
15	North Lincolnshire Council	8	65	288	**393**	149	24	18	945	34	376
16	**North Yorkshire County Council**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
17	Richmondshire District Council	1	3	26	**74**	49	14	5	172	32	380
18	Rotherham Metropolitan Borough Council	4	53	173	**436**	392	128	87	1,273	164	1,733
19	Ryedale District Council	3	13	27	**61**	36	4	2	146	31	311
20	Scarborough Borough Council	9	26	136	**193**	82	32	15	493	63	759

21	Selby District Council	1	6	55	**168**	60	29	8	327	57	592
22	Sheffield Council	10	131	427	**572**	319	146	120	1,725	15	352
23	Wakefield City Metropolitan Borough Council	14	67	201	**382**	297	124	119	1,204	75	1,003
	Total	170	1,388	4,569	**7,898**	5,330	1,962	1,342	**22,659**	1,318	15,583
	% of Total DECs Rated 'A'	≈ 0.750 %									
	% of Total DECs Rated 'B'	≈ 6.126 %									
	% of Total DECs Rated 'C'	≈ 20.164 %									
	% of Total DECs Rated 'D'	≈ 34.856 %									
	% of Total DECs Rated 'E'	≈ 23.523 %									
	% of Total DECs Rated 'F'	≈ 8.659 %									
	% of Total DECs Rated 'G'	≈ 5.923 %									
	% of Total PRs w/ 'Fabric-1st'	≈ 8.458 %									

DEC Ratings and AR 'Fabric-1st' Priority Recommendations for Northern England

Table 5 illustrates the summary statistics obtained from the DEC Ratings and AR 'FabricFirst' Priority Recommendations for Northern England. As can be seen from Table 5, there is a spread of performance. However, it is notable that the least total DECs for Northern England were rated 'A', 'G', 'B', and 'F' whereby the total percentages of such DECs are about 2.208 %, 15.263 %, 17.737 %, and 23.422 % respectively. This is a similar pattern to those of its three regions, that is, the North East, North West, and Yorkshire and Humber.

The second and third most total DECs for Northern England were rated 'E' and 'C' whereby the total percentages of total DECs rated 'E' and 'C' are about 67.725 % and 63.788 % respectively. This is a similar pattern to those of two of its three regions, that is, the North West, and Yorkshire and Humber. In the case of the North East, this pattern was 'C' and 'E'.

The majority of total DECs for Northern England were rated 'D' whereby the total percentage of total DECs rated 'D' for Northern England is about 109.866 %. This is a similar pattern to those of Northern England's three regions, that is, the North East, North West, and Yorkshire and Humber whereby the majority of DECs were also rated 'D'.

In regards the Government Property Unit (2013) target for buildings to attain DEC 'A' to 'D' ratings by 2018, Table 5 shows that the target will not be met by the total percentage of total DECs rated 'E', 'F', and 'G' for Northern England, which is about 106.41 %.

In regards the 'Fabric-First' approach to energy efficiency, Table 5 shows that the total percentage of total AR Priority Recommendations for Northern England related to 'FabricFirst' is about 26.374 %.

Table 5: DEC Ratings and AR 'Fabric-1st' Priority Recommendations (PRs) for Northern England

		Approximate (≈) Percentage (%) of Total DECs Rated 'A' (Most Energy Efficient) to Rated 'G' (Least Energy Efficient)							≈ % of Total AR PRs Related to Fabric-1st Approach
		A	B	C	D	E	F	G	
	Northern England Regions								
1	North East England LGAs	0.843	6.195	23.953	**36.782**	20.368	7.109	4.751	7.704
2	North West England LGAs	0.615	5.416	19.671	**38.228**	23.834	7.654	4.589	10.212
3	Yorkshire & Humber LGAs	0.750	6.126	20.164	**34.856**	23.523	8.659	5.923	8.458
	Total	2.208	17.737	63.788	**109.866**	67.725	23.422	15.263	**26.374**
	Total % of Total DECs Rated 'A'	≈ 2.208 %							
	Total % of Total DECs Rated 'B'	≈ 17.737 %							
	Total % of Total DECs Rated 'C'	≈ 63.788 %							
	Total % of Total DECs Rated 'D'	≈ 109.866 %							
	Total % of Total DECs Rated 'E'	≈ 67.725 %							
	Total % of Total DECs Rated 'F'	≈ 23.422 %							
	Total % of Total DECs Rated 'G'	≈ 15.263 %							
	Total % of Total PRs Related To 'Fabric-1st'	≈ 26.374 %							

CONCLUSION

This paper is part of a D.Eng. research into Central and Local Government Compliance with DECs and ARs in England and Wales. Summary statistics have been produced on DEC and AR ratings, lodgement, and 'Fabric-First' priority recommendations of LGAs in Northern England for 2008 to 2017. This is the first independent synthesis of data of this kind, which provides evidence on DEC and AR Local Government compliance in Northern England.

Guidance was adopted and adapted by this paper for its Protocol for Quantitative Analysis of Local Government DEC and AR Compliance, which was non-experimental, and made some significant findings. For instance, the headline findings include that: 7.2% of the 375 LGAs in England and Wales appear not to have lodged DECs and ARs via the OpenDataCommunities Platform; While none of the 22 LGAs in Wales have DEC and AR nonlodgement, 27 of the 353 LGAs in England have DEC and AR non-lodgement; The majority of DECs for the North East, North West, and Yorkshire and Humber regions of Northern England were rated 'D' with about 36.782%, 38.228%, and 34.856% respectively; The percentage of total DECs for these regions that will likely not meet the Government Property Unit target to attain DEC 'A' to 'D' ratings by 2018 are 32.228%, 36.077%, and 38.105% respectively; and The percentage of total AR Priority Recommendations for these regions that are related to the 'Fabric-First' approach are about 7.704%, 10.212%, and 8.458% respectively. These are significant, as it underlines likely difficulties that may be faced should minimum energy performance standards be introduced at a future date.

The implication of such difficulties with compliance at this regional level is that the DEC and AR are not yet being fully complied with (or enforced) as originally intended by the principle underlying the Energy Performance of Buildings Directive (EPBD).

Future work will include: synthesis of quantitative evidence on DEC and AR LGA compliance in Wales and other regions of England; and creation of a Protocol for Qualitative Analysis of UK Government DEC and AR Compliance. These will help determine why DEC and AR poorratings, non-lodgement, and 'Fabric-First' priority recommendations occur for UK Central Government and LGAs in England and Wales.

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USE OF UAVS FOR RENEWABLE ENERGY PROJECTS

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Abstract

This paper looks into the opportunities for robotic technology uses in the construction of solar projects. Following the current high demand in the solar construction industry, skilled labor shortage due to the recession has imposed significant challenges to the industry. This paper highlights potential uses of robots to alleviate some of these challenges based on the overall cost reductions, quality management, ease of use, and impact on subsidizing or replacing human labor. The main research methods incorporated in this study were a literature review and survey analysis of industry professionals. The quantitative analysis of the survey results as well as literature review clearly indicates that professionals in the solar industry are open to the idea of robotic technology, but are not aware of the current available advanced technologies and potential uses and benefits of different kinds of robots such as Unmanned Aerial Vehicles (UAVs), commonly known as drones.

INTRODUCTION

The solar construction industry is currently experiencing a booming market following the recovery from the recession, and interestingly "there are more people working in solar, than on oil rigs or gas fields" (Gillespie, 2016). As a result, a rapid increase in demand has made the industry more vibrant and welcoming to the graduating mass. With all the available employment opportunities, surprisingly the industry is witnessing a significant decrease in the number of both laborers and skilled workers, which has created a labor shortage within the solar construction industry's working force (Janicki, 2015).

Since The Great Recession, construction workers have been difficult to find because roughly 60% of workers had been displaced or found work in different industries. Less young people have chosen a career in construction, highlighted by a studied that showed the percentage of construction workers below the age of 45 dropped from 73% to 62% (Janicki, 2015). A few researchers anecdotally report that the use of robots seems to have the right solution to this problem. Several countries such as Israel, China, Japan, and some parts of the US have started

to utilize these machines. They use robots and drones in the construction, inspection, and maintenance of solar panels (Cardwell, 2013). Companies are spending a lot of money to send employees to solar field sites, running the risk of human labor skewing the precisely placed panels, most of which are located in very remote and unsafe locations (Shamah, 2014). With the current decrease in the physical manpower, the puzzle becomes even more complex and it is yet to be solved. This paper will investigate how robots can be used to alleviate the effects of this growing labour shortage in the construction industry's working force and recommend ways to make solar field projects more efficient.

LITERATURE REVIEW

The literature review revealed that this decrease in the supply of construction workers has driven up solar farm construction costs greatly. The demand for solar field workers has greatly increased, and with this recent up-cropping of solar projects, there are now more people working in solar, than on oil rigs and gas fields. The solar workforce is now close to being three (3) times the size of the coal-mining workforce (Gillespie, 2016). The overall decline of worker availability and the upswing in demand opens the door for robots to become a commonality in the solar industry; the results of the survey concur with these findings. One of the professionals who responded to our survey asserted that "The shortage [of labor] isn't in management, it's in craftsman, and the issue isn't specific to solar. In general, there is a huge shortage if trade labor in the industry"

In a trial implementation of installation robots, conducted by the company Brodebeck and Kenner Maschinenbau, their panel mounting robots were found to be able to replace two hundred fifty (250) laborers during the construction of a one hundred (100) megawatt plant, proving that robots can be a viable replacement for workers (Woody, 2012). According to 2015 study, robots, like computers, are becoming increasingly cheaper and are a reasonable alternative to human workers (Thurston, 2015).

Mortenson Construction and RDO Equipment Co. teamed up to perform research on the accuracy of information gathered by Unmanned Aerial Vehicles (UAVs), as well as to analyze the efficiency of UAVs in surveying compared to traditional methods. Using UAVs to gather topographical information, Mortenson found data to be 84% more accurate and was gathered 47 hours faster than traditional vehicular methods (Maloney, 2016). Drones are also able to gather more data at once, compared to traditional vehicular crews, using new heat imaging sensors, GPS, LiDAR, and built in cameras. These drones have fixed and predictable costs making budgeting easier and can make solar fields safer by increasing the frequency of inspections (John, 2015).

Robots can also be used in the daily operation of these solar fields. Because most solar fields are within harsh desert climates, robots can be utilized in the cleaning of solar panels; as panels are more frequently cleaned, their efficiency increases making more power and saving money (Cardwell, 2013). Panel cleaning technology has also been implemented in several Israeli solar plants. These cleaning robots use large rubber screeds to remove dust and dirt from panels, eliminating the need for water, a scarce desert resource, and increasing the production capability of the panels (Shamah, 2014). One of the respondents to the survey pointed out that

"Inspection [and quality control] has the largest shortage of skilled labour." Overall, the literature review gave the opinion that there currently is a lack of solar field workers and an increase in demand for them. It has been found that robots can save time, increase efficiency and production, and make solar fields safer.

Current Robot Technologies

One of the respondents asserted that "Most fields (not fixed) use a tracking system which could be considered robotic (look-up NEXT tracker or Soltec). The best opportunity in my mind is prefabrication in union environments. Almost every [California] project utilizes a 5 party [Project Labor Agreement] resulting in a composite rate of $60+ an hour. If robotics can be used in a warehouse offsite to prefabricate systems in order to eliminate labor hours in the field there is significant opportunity for cost savings." This response indicated the willingness of the professionals to consider the use of robots in cutting down the use of human labor force in the construction industry. This section will highlight the implementation of robotic technology in the solar construction industry. The implementation process described in this section focuses mostly on the use of Unmanned Aerial Vehicles (UAV), commonly known as drones, which are the kinds of robots currently used the most in the solar industry. Moreover, this section will also highlight other kinds of robots; which have already proven to have some uniqueness for revolutionizing the future of the solar industry.

Unmanned Aerial Vehicles (UAV) come in several shapes and sizes. The larger the drone, the more stability, battery life, and weight-bearing capacity it will offer. These UAVs can be used at different stages of solar construction including land survey, monitoring and documenting project progress and conditions, inspections, investigations, marketing/public relations, and panel cleaning (Hickman, 2016). Panel cleaning is always a challenge for solar projects since it is time consuming and it has to be done at night in order to prevent loss of production.

Figure 1: Rotary-Blade UAV

The two most common types of UAVs, which are generally used in construction are Rotary-blade UAVs and Fixed-wing UAVs. However, Rotary-blade UAVs are much more common in solar construction and other commercial applications than fixed-wing UAVs. Rotary-blade UAVs as shown on Figure 1, look and function similar to helicopters, and they have vertical take off and landing (VTOL) capabilities as well as the ability to hover the place. Furthermore, Rotary-blade UAVs are available in single- or multi-rotor designs, with additional propellers which give

them greater stability and weight-bearing capacity. However, Rotary-blade UAVs have lower speeds, lower battery life, greater mechanical and electrical maintenance requirements, and shorter range flight capabilities than Fixed-wing UAVs which have high speeds and long distances flight capabilities, and can carry heavier payloads. A shown on Figure 2, Fixed-wing UAVs although they have all previously described abilities, they need runways for landing and taking off and also they can't hover which make them unsuitable for solar and other commercial construction applications such as inspections.

Figure 2: Fixed-Wing UAV

The use of UAVs on the Utah Sun Edison solar projects proved the efficiency on survey data capture. Survey data is one of the critical elements for overall performance of solar fields. All single axis tracker technology must be leveled in the north-south and east-west direction to prevent shading. In large arrays, trackers heights should be planned in order to prevent one tracker from shading another tracker as well as preventing both trackers from pitching to the north. Additionally, the use of UAVs was found to enhance the methods of data collection and analytics (Maloney, 2016).

The UAVs were used to gather aerial imagery, which was processed with photogrammetry technology to generate topographical data of both a finish grade and a rough graded solar site. In this 350acres solar project, a Fixed-wing UAV was used instead of Rotary-blades UAV. For a total of five-thirty six minutes flights, which were made, two billion data points were collected and the approximated project cost was $1,500 (Maloney, 2016). Moreover, compared to the terrestrial survey method, the use of the UAV was found to have 300 topographic density improvements, 84% topographic accuracy improvement, 40 hours of time investment improvement, and $8,500 of project cost savings. UAV was found to cut down time significantly for data collection especially in vegetated site. Assuming that the vegetation is sparse enough to see the ground at a regular interval, the use of UAV was found to require 3 hours of data capture compared to 50 hours of terrestrial data capture (Maloney, 2016).

Benefits of Robot Technologies

Just like in other fields, the adoption of new technologies generally has a large upfront cost, but has long-term benefits and predictable returns on investment. This section aims to look at an overall benefit in cost and quality.

Cost of human labor is the single most expensive part of solar farm operations. From the survey analysis, it was found that 59 percent of respondents agreed that human labor during the construction and maintenance of solar field projects comprised a majority of the total costs. Maintenance crews require transportation to various locations on large projects, which includes: Trucks, fuel, insurance, specialized personal protective equipment (PPE), benefits, etc. It was found that every time an employee needed to be sent into the field for an inspection, costs between $300 and $600 (John, 2015).

The cost of implementing inspection drones can vary greatly depending on location and capabilities. Inspection drones vary from fixed winged to having 8 rotors, and cost between $16,000 and $100,000 depending on location and vendor (John, 2015). When comparing these costs, it is important to understand that the quality and frequency of inspections increases compared to traditional methods conducted via truck. These drones capable of collecting more data per flight than a typical inspection crew because they utilize, heat imaging sensors, on board cameras, LIDAR (which has been used to increase inspection quality in bridge projects across the country), and GPS tracking (John, 2015). Combine these benefits with the more frequent inspections/flights and drones provide a great benefit to its users.

The routine cleaning of solar panels is also expensive. Due to the remote location and immense size of most solar fields, cleaning crews are both expensive and unproductive. Because solar fields become inefficient and unprofitable when panels are dirty, this is a crucial task in the solar farm's success (Shamah, 2014). The implementation of panel cleaning robots in the Kibbutz Ketura, Israel Solar field has not only saved money on by utilizing panel cleaning robots, but has also increased power production by up to 35% as a result (Shamah, 2014). The cost reduction in cleaning due to the utilization of these robots, allow the panels to undergo routine maintenance much more often than traditionally. Some panels were only cleaned nine times a year before the implementation of the robotic cleaning system, and thus increased the degradation rate of the panels and reducing their useful life. The cleaning quality and frequency helps increase panel life, power production efficiency, and reduce cost by replacing expensive maintenance crews (Shamah, 2014).

From the few solar farms that were investigated, drones and robots have been a viable and profitable solution to the expensive use of human labor on these projects. The overall quality of the robots' service was also generally greater than that of their human counterparts. With better solar panel design and manufacturing methods, human labor will only become a bigger portion of solar field costs making the use of robotics even more desirable.

RESEARCH METHODOLOGY

The research explores opportunities for robotic use as a solution to the decreasing number of field laborers in the solar field, as well as identifies the cost, time saving, and safety benefits of utilizing robots in solar field projects. A survey has been conducted to collect views from professionals, in the solar power construction industry, about the use of robots onsite and to identify their most beneficial uses. The survey was sent to 449 professionals at construction companies, which are interested in the solar power. Statistical analysis was used to analyze the

data received from the survey, and both the survey results and literature review findings were used to interweave the findings from the survey and various literatures into tangible conclusions.

Out of the 449 construction and solar industry professionals, to whom the survey was sent, 58 responded, leading to a response rate of 12.9 percent. The majority of respondents (67 percent), hold a Bachelor's Degree and 29 percent hold a Master's Degree or above. 78 percent of respondents also currently work in the Midwest. The data shows the belief that construction is the most expensive aspect of a solar field, according to 59 percent, as supported by the 68 percent which responded with construction currently having a labor shortage.

RESULTS

One of the questions related to the demographics of the survey group was regarding who actually has experience in the solar industry. When those who answered yes are compared with those who answered no, some interesting results become apparent. One such result, while not necessarily relating to our topic, is that 48 percent of the people that said they do not currently work in the solar industry would be willing to consider a career in solar construction, which shows that there is vested interest in the field, allowing for continued growth. When reviewing the answers of those with solar experience, the main reason for the solar labor shortage was found to be the lack of skilled labor and the remote locations of projects. While unskilled labor might be available, the work is hard and drives people to find other industries. The remote locations of projects are of no help either, as this relatively new industry does not have a skilled workforce around the country.

	Would Use Robots due to Labour Shortage		**Have Used Robots on Projects**		**Robots Would be More Economical**	
	Yes	No	Yes	No	Yes	No
Solar Experience	50%	50%	29%	71%	43%	57%
No Solar Experience	73%	27%	22%	78%	53%	47%

Table 1: Significant Survey Results

As shown on Table 1, those with solar experience were found to be split on whether they would consider robotics filling that shortage. However, those without industry experience were found to be much more open to the use of robotics. From this, while there is a definite use of robotics in the solar industry, there is also further research, which could be done regarding the use of robotics in other construction industries. From the responses of those with experience regarding whether the technology was advanced enough, a respondent mentioned that in their experience, many companies are not willing to put money into research and development of the technologies. However, from the literature found on the subject, it appears that the robots are available, but there may not widespread information about them yet, as they all seem to be recent development. As such, the industry may just need to wait another year, as various

companies continue to develop their technologies and make them more available around the globe, especially as only 29 percent of those with experience answered as having used robots for their projects.

When considering the cost of automating the construction of solar fields, 57 percent of those with experience believe that automating it would be more costly than it currently is. This shows that more work needs to be done on the current technologies, bringing them into a more cost effective price range, allowing for more companies to use them. Along with that, 71 percent of those with experience believe that the construction of a solar field is the most costly aspect, as compared to the maintenance, inspection, safety, or quality control of a solar field. On the useful side of robotics, 50 percent of those with experience believed that the best use of robots would be in the rotating and tilting of panels for maximum sun exposure, as well as in the cleaning of panels. This also coincides with those who do not have specific solar experience, as 75 percent of those respondents believed that robots would be most useful in the rotating and tilting of panels and 63 percent believed that using robots for the cleaning of panels would be most beneficial for solar projects. So while robots may not be quite ready to be received by the solar industry, there is still a beginning lean towards them, as labor shortages rise and robots become more cost effective.

CONCLUSION

"Technology exists (sunpower has some for maintenance) but at least on the construction side of things I think there is a lack of willingness to put the $ into [Research and Development] for developing the task specific robots. Technology also changes incredibly fast so something you spend a lot of time developing could be obsolete by the time it's done." This was one of the strong comments from our survey respondents. There are many opportunities for robotic technology uses in the construction of solar projects. With the many advances being made in robot and drone technology, the robots are often more precise than the use of construction laborers, making them more beneficial. The lack of awareness about the currently available advanced robotic technology among the professionals, has limited their willingness to invest on using robots in the construction of solar projects. With all these opportunities for robot uses, there still needs to be a more broad awareness of the current robotic technologies, letting companies know of the options.

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Energy

ENERGY - AWARE CLOUD INFRASTRUCTURE FOR IOT BIG DATA PROCESSING

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Keywords: IoT Big Data Analytics, Cloud Data Centers, VM consolidation, Power Usage Characteristics

Abstract

Internet of Things (IoT) is an outcome of the emanating third wave of development of the Internet. Big Data Analytics in IoT provide valuable insights for Smart and Sustainable systems. Cloud Data Centers deliver on-demand computing resources for processing voluminous data. Servers that are provisioned for this purpose consume enormous amount of energy contributing to 2% of the global Carbon-dioxide (CO2) emissions. IoT energy concerns are addressed by research in low-power sensors and improved Machine-to-Machine communications. However, Cloud Data Centers still face energy crisis. This work attempts to analyze the energy behavior of compute hosts on applying Virtual Machine (VM) Consolidation in a Multi-node Openstack Cloud. Several works on VM consolidation is evaluated for simulated workload but this work aims to study the performance in a real cloud infrastructure with a big data workload. The preliminary results of this research are presented in this paper.

INTRODUCTION

With the advent of the cloud computing paradigm providing utilities over the internet for processing big data from Internet of Things (IoT) devices and sensors in the last decade, there is an exponential growth in user demands and generated data (Bushweller, 2017). Gartner 2014 predicts that IoT will hit mainstream by 2020 with almost 25 billion smart objects generating data. In order to meet the demand, IT infrastructures such as data centers play a crucial role in providing elastic resources. As a consequence, there is need for humongous amount of energy to power the ICT equipment. Increasing energy needs implies need for more coal and fossil fuels to generate energy. Statistically, energy consumption of data centers all over the world has increased by 56% within a short span of five years between 2005 and 2010 (Koomey, 2008). According to Gartner 2007, data centers contribute to 2% of the global carbon-dioxide emissions which is almost the same as that of the aviation industry. This trend is not sustainable as the situation directly impacts the global carbon emissions from energy generation. Green Computing focuses on optimizing computing technologies and practices to reduce negative impact on the environment without compromising performance (Zhu *et al.*, 2015). VM consolidation is one of those green practices where the number of active computing devices are reduced turning the inactive servers to an energy saving mode (Sami *et al.*, 2015). Infrastructure as a Service (IaaS) providers consider a number of metrics to define their performance to meet the Service Level Agreement (SLA). In case of an IoT system that requires a Big Data processing platform on cloud, resources need to be elastic to meet the needs. Analysis of VM consolidation for such a dynamic system using the performance and energy metrics can provide useful insights towards building an energy aware infrastructure.

RELATED WORK AND UNDERLYING CONCEPTS

While several research works have contributed towards Green IoT and Green Computing techniques, the scope of this paper is to study energy efficient systems and methods at a data center infrastructure level.

GREEN IoT AND BIG DATA

IoT being a pervasive technology, its effects on environment should also be taken into account (Routray and Sharmila, 2017). For long term use, the whole system has to be optimized for energy efficiency and resource utilization. Radio-frequency identification (RFID), Machine to Machine (M2M) communications, green cloud computing and data centres are the key focus areas for green computing (Zhu *et al.*, 2015). The goals of data processing are to make faster decisions, provide reliable results with low latency for batch and stream processing and sophisticated methods for making 'better' decisions (Standards and Council, 2014). In order to achieve these goals, powerful platforms are imminent. Hardware and software play crucial role in attaining the goals. IoT data is voluminous and complex for which scalable systems are needed (Jimenez-peris, 2016). CPU time, I/O time, storage resources and energy efficiency are a few constraints for efficient data processing.

CLOUD DATA CENTERS

ICT infrastructures and cloud providers are looking for effective systems and methods to face the overwhelming utility bills and their carbon footprint (Dayarathna *et al.*, 2016). The goal of computing infrastructure industry has shifted to energy efficiency along with QoS for customers. End-users have an impact in terms of increased resource usage costs which is decided based on the total cost of ownership (TCO) by the provider (Moreno and Xu, 2011). Higher energy consumption not only increases utility bills but also impacts the requirement of more cooling systems, uninterruptible power supplied (UPS) and power distribution units (PDU). Several studies have shown that reducing power consumption of a system effectively extends the overall running time which results in longer lifetime of the device (Daud *et al.*, 2014).

Most cloud data centres use blade servers which provide more computational power and less space consuming. However, blade servers are hard to cool as the components inside are densely packed. In line with an example stated in (Beloglazov *et al.*, 2011), 60 blade servers can be mounted to a rack of 42U. On the contrary, the rack requires up to 4000 W for power supply to the servers and cooling systems compared to a rack with 1U servers which require only 2500 W. Data center sustainability and efficiency measures are listed down in (Masanet and Robert, 2015). Power infrastructure, Cooling, Airflow Management and IT efficiency are the key factors that determine the efficiency of a data center. Power Usage Effective (PUE) and Data Center Infrastructure Efficiency (DCIE) are the widely used energy efficiency metrics originally proposed by Greed Grid Consortium. PUE is a ratio of energy consumed by the data center to

the energy supplied to the computing equipment. DCIE is the inverse of PUE (Masanet and Robert, 2015).

ENERGY EFFICIENT COMPUTING SYSTEMS

Gordon E. Moore in the year 1965 stated *"With unit cost falling as the number of components per circuit rises, many as 65,000 components on a single silicon chip"* (Gordon E. Moore, 1965). With increase in the number of components, size has decreased and speed has increased. This is applicable to the increase in number of cores in a CPU (Travers, 2015). Increased speed is invaluable for mission critical tasks but the need for more energy affects the system adversely.

For energy proportional computing, it is important to know the relationship between workload and power consumption of multi core processors. For single-core processor, the relationship is approximated by a quadratic function and on the other hand, the relationship is approximated by a linear function for dual core processor (Dargie, 2015). A study on benchmarking power usage characteristics of embedded processor and analysing the idle power consumption shows that the energy consumed by the processor significantly diminishes instantly as the processor enters an idle state (Daud *et al.*, 2014). This study also states that during the idle time, energy consumption reduces without invoking hardwarebased frequency scaling or DVFS methods thus being effective with less overhead (Cao and Zhu, 2013).

CLOUD RESOURCE MANAGEMENT

Data centres computing infrastructure consists of three main divisions, application domains, computing environments and physical resources (Beloglazov *et al.*, 2011). Virtualized and non-virtualized resources provide the necessary computing resources. Resource Management in a Cloud Data Center comprises of Ab-initio Resource Allocation and Periodic Resource Optimization. The periodic resource optimization involves continuous resource monitoring and VM consolidation (Caglar and Altilar, 2016).

CONSOLIDATION OF VIRTUAL MACHINES

VM consolidation is a potential solution for improving resource utilization and reducing energy consumption (Khoshkholghi *et al.*, 2017)(Caglar and Altilar, 2016). Virtualization lets cloud providers provision multiple virtual machines on a single physical host (Beloglazov, 2013). As a result, resources are utilized in a better manner thus increasing the Return On Investment (ROI) (Beloglazov *et al.*, 2012). VM consolidation technique achieves energy saving by eliminating idle power consumption. It is done by switching idle hosts to low power mode such as sleep or hibernate modes (Ashraf *et al.*, 2016). VM consolidation is a complex decision-making problem that involves four sub-problems: underload detection, overload detection, VM selection and VM placement (Abdelsamea *et al.*, 2017). Detection underload and overload conditions, deciding on VMs to be migration when done in realtime, is called dynamic VM consolidation (Khoshkholghi *et al.*, 2017). Several works propose algorithms for underload and overload detection based on a threshold, statistical analysis and fuzzy logic and regression

based prediction models (Abdelsamea *et al.*, 2017)(Sami *et al.*, 2015). Random selection, Minimum migration time, regression based selection are a few of the VM selection algorithms (Hieu *et al.*, 2015)(Abdelsamea *et al.*, 2017). The proposed algorithms are tested on simulated cloud environment using simulation tools like CloudSim (Beloglazov *et al.*, 2012) on simulated workloads with CPU traces from PlanetLab or Google Cloud Datastore (GCD) (Abdelsamea *et al.*, 2017)(Hieu *et al.*, 2015). The performance is not tested on real cloud infrastructure. This research aims to evaluate the strategies on Openstack cloud as it is a potential cloud platform for big data processing (Corradi *et al.*, 2014)(Dai *et al.*, 2016). The open-source nature of the platform provides capabilities to tweak the system for energy efficiency using APIs of compute service Nova. Openstack NEAT is dynamic VM consolidation framework developed as an add on package for Openstack instances (Beloglazov and Buyya, 2015). The framework is proposed in (Beloglazov and Buyya, 2015) but is not evaluated for big data workloads.

METHODOLOGY

Methodology directs the study towards attaining the objectives to model a cloud platform for IoT big data analytics using open-source tools and to test VM consolidation on real cloud infrastructure. The methodology of this work is largely split into four parts: Identifying research gaps in the area of energy efficient computing systems for IoT Big data processing through literature review, formulation of aim, objective and scope of the research, the design of the cloud system and setting up the cloud - IoT infrastructures and conducting experiments on compute hosts, obtaining and analyzing baseline data which is useful for further evaluation of specific strategies.

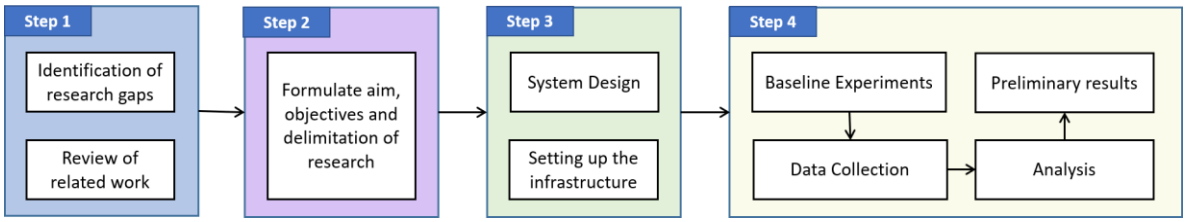

Figure 1. Methodology

CLOUD SYSTEM ARCHITECTURE

In order to effectively evaluate the advantages of VM consolidation for energy saving, it is important to test them on a real cloud infrastructure. We propose a tiered cloud model based on open-source tools and platforms such as Openstack, Apache Spark and Openstack NEAT (Beloglazov and Buyya, 2015). An IoT system with sensors and devices is integrated with the proposed system. The data is sent to the cloud platform using REST API. Other messaging protocols such as MQTT or CoAP can also be used. The proposed system architecture is depicted in figure 2.

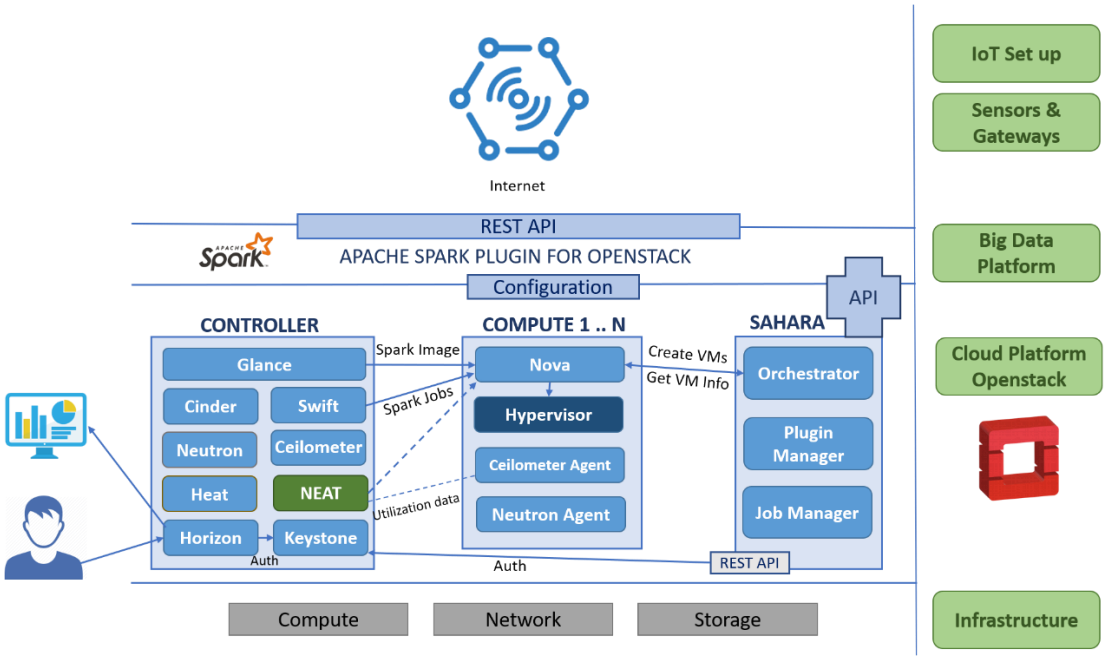

Figure 2. System Architecture

The bottom most tier is the physical infrastructure consisting of compute, network and storage resources. Openstack cloud platform is deployed on the infrastructure to virtualize the resources. Openstack is an open-source platform for creating and managing cloud infrastructure which is commonly used by IaaS providers (Corradi, Fanelli and Foschini, 2014). Openstack project was begun with an aim to build a "massively scalable cloud operating system" (Litvinski and Gherbi, 2013). It is built on the concept of distributed system with asynchronous messaging. It consists of seven major services for compute, storage, network, monitoring, orchestration and image along with authentication and dashboard services. The compute services consist of a web-based API, controller and scheduler. Compute controller is responsible for managing VMs on compute hosts. For the purpose of modelling a system, we created a four-node cloud set up with one controller and three compute nodes. The hardware configuration of the system is presented in the table 1.

Host Name	Device	Processor	Operating System	Memory	OS Type	Disk
Controller	HP Proliant DL360p Gen8	Intel Xeon ® CPU - E5-2620 0 @ 2.00 GHz * 24	Ubuntu 16.04 LTS	70.8 GiB	64-bit	219.1 GB
Compute1	HP Compaq Elite 8300 MT	Intel Core i7-3779 CPU @ 3.40 GHz * 8	Ubuntu 16.04 LTS	15.5 GiB	64-bit	487.7 GB
Compute2	HP Compaq dc7900 SFF	Intel Core 2 Duo CPU E8400 @ 3.00 GHz * 2	Ubuntu 16.04 LTS	3.8 GiB	64-bit	242.9 GB
Compute3	HP Compaq dc7900 SFF	Intel Core 2 Duo CPU E8500 @ 3.16 GHz * 2	Ubuntu 16.04 LTS	3.6 GiB	64-bit	242.1 GB

Table 1. Configuration of the servers

The data obtained from the IoT system is processed as Spark jobs. The in-memory data processing engine which is suitable for both batch and stream processing, Apache Spark is used as the big data platform (Lopez, Lobato and Duarte, 2016). Sahara is the renamed Openstack project Savanna which provides a means to provision big data application cluster on Openstack. The plugins that are available for creating data-intensive application cluster are Hadoop, Spark and Storm. When a cluster is configured and launched, sahara orchestrator sends a create VM request to nova which in turn requests 'glance' for apache spark image. Virtual Machines are

launched by communication to the hypervisor (KVM) launched and orchestrated by heat. The data and job to be processed are stored in the object storage swift. The spark jobs are then obtained by Nova API and processed by the infrastructure managed by sahara job manager.

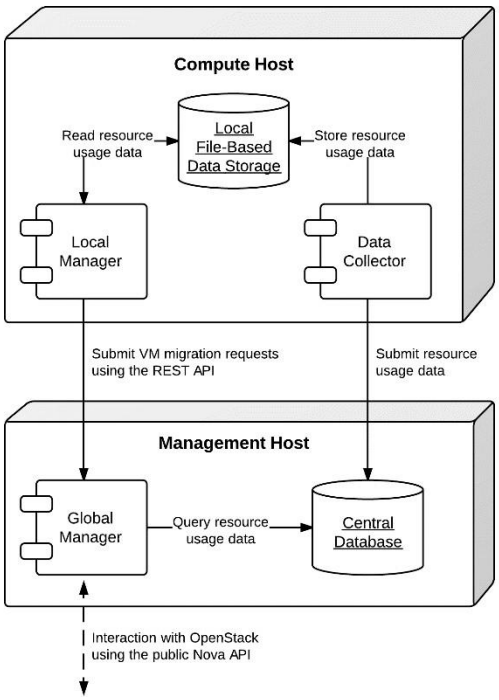

Figure 3. Components of Openstack NEAT (Beloglazov and Buyya, 2015)

The controller node consists of the controller component of each service. In addition to basic openstack services, NEAT Global Manager also runs in the controller. NEAT consists of a Global Manager deployed on the controller node which makes decisions on mapping virtual machines to compute hosts and initiating migration of the selected VMs. A Local manager runs on each compute host which makes decisions on underload or overload situations and VM selection for migration. A data collector is another component that runs on compute nodes to collect resource utilization data from hosts and hypervisors and sending the data to the central database in the controller. Figure 3 shows the components of Openstack NEAT.

EXPERIMENTS

To compare the energy efficiency of the system with VM consolidation, it is important to analyze the basic power usage of the compute nodes. A basic set of experiments are run on the infrastructure to identify the power usage characteristics. The idle power consumption of the controller and the compute nodes are presented in table 2.

Server	Power Consumption (Watt)
Controller	6.2
Compute1	2.4
Compute2	1.9
Compute3	1.8

Table 2. Idle Power Consumption

The set of experiments are run with simulated load generated using stress-ng. It is a stress test utility to test OS interfaces and sub-systems (Zhan, 2015). The peak power consumption of the controller and compute nodes are observed for different CPU intensive, generic input/output and RAM (Virtual Memory Stressor) workloads. The experimental set up for conducting baseline experiments is shown in figure 4.

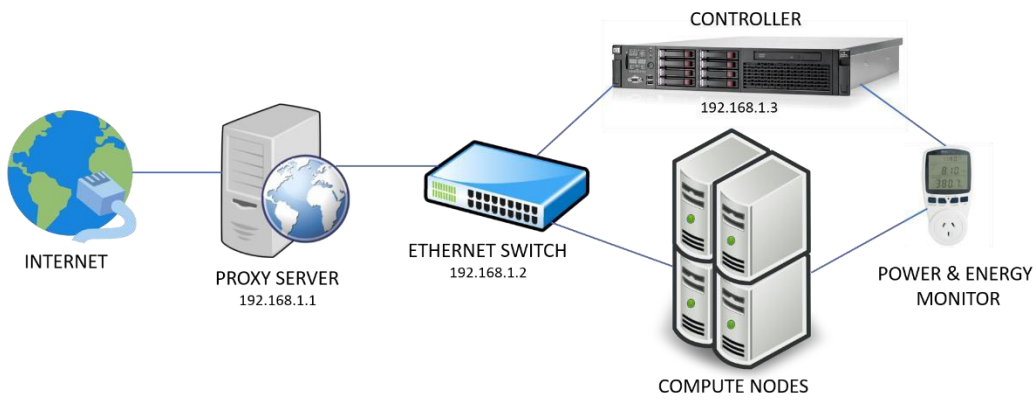

Figure 4. Experimental set-up

In order to measure the power consumption of the nodes, the controller and the compute nodes are plugged into the power source through plug-in power and energy monitors. The nodes are connected to the internet through a secure proxy server. Two Network Interface Cards (NICs) are present for each node, NIC1 provides access to the internet whereas NIC2 is connected to the Management or Internal network. The public IP obtained by each virtual machine is called floating IP address in Openstack terms (Corradi, Fanelli and Foschini, 2014).

The design of experiment for this research has three phases: Plan, Execute and Analyze. The aim, objectives and expected outcome are defined and the required equipment is identified in the 'plan' phase. The experiment is executed for repeated runs or repeated for a specified amount of time. Data is collected at the end of each experiment and stored. The collected data is analyzed, interpreted and validated. The findings are documented for further study.

RESULTS AND DISCUSSION

As discussed in the previous section, stress-ng is used to synthetically overload the compute nodes with CPU, I/O and RAM workloads. The number of cores to be stressed, number of I/O tasks and amount of RAM are provided as input. The experiment is conducted for a time-period of 60 seconds. Workload is applied in percentages from 0 to 100 in an interval of 10. This experiment is repeated 10 times and the peak power consumption is observed.

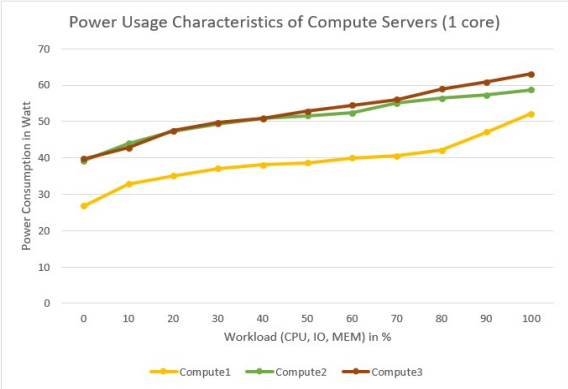

Figure 5. Power Usage Characteristics of Compute Servers (1 core)

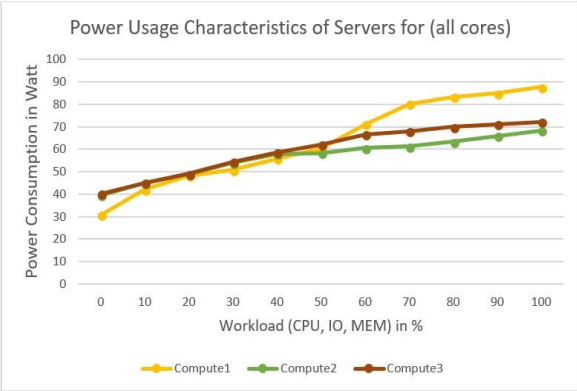

Figure 6. Power Usage Characteristics of Compute Servers (all core)

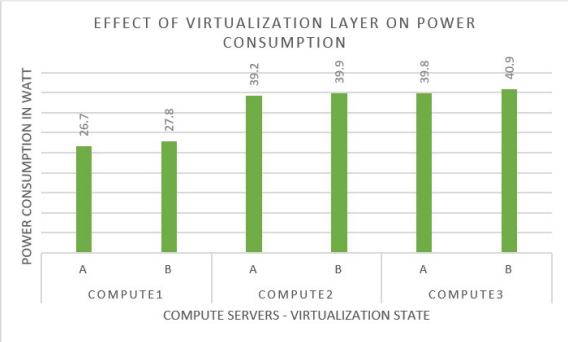

Figure 7. Effect of Virtualization on Power Consumption

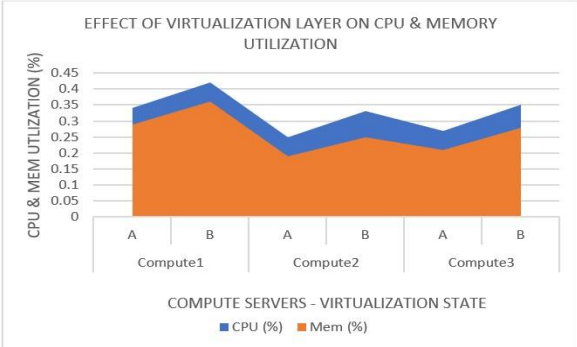

Figure 8. Effect of Virtualization on CPU and Memory utilization

Figures 5 & 6 depict the peak power usage characteristics of the compute nodes for varied workloads. For similar workloads, the energy behaviour of a server with single core and that with multiple-cores are different (Travers, 2015). The stress was applied on a single core and all cores of the compute hosts to observe the difference. Compute1 has an Intel Core i7-3779 CPU @ 3.40 GHz with 8 cores whereas Compute2 is Intel Core 2 Duo CPU E8400 @

3.00 GHz with 2 cores and Compute3 is Intel Core 2 Duo CPU E8500 @ 3.16 GHz with 2 cores. From figure 5, it is evident that Compute1 consumes less power compared to the other compute nodes when one of the cores is stressed. The i7 processor is optimized for power consumption compared to the core2duo processors (Travers, 2015). On the contrary, when all the cores are stressed, the energy behaviour of compute1 changes drastically when the workload is increased to 60%. The turbo boost feature of i7 processor is responsible for this behaviour. The turbo boost feature of i7 processors reduce up to 6% percent of the execution time at the cost of increasing the energy consumption by 16% (Charles *et al.*, 2009). On comparing compute2 and 3, the energy behaviour is similar till the workload is 50% for both cases from figures5 & 6. Compute3 tends to have a higher power consumption when the workload varies from 60 to 100%. This can be attributed to the electronic hardware ageing. From the above analysis, it is clear that in order to reduce power consumption of the nodes during data processing, it is important to reduce the peak power consumption by efficiently

identifying the underloaded and overloaded hosts and reducing the number of active hosts by putting the others to an idle mode. The idle mode power consumption of the compute nodes is negligible as shown in table 2.

It is often argued that virtualization causes overhead on servers. Several works throw light on understanding the overhead caused by virtualization (Chen *et al.*, 2015). In this paper, it is relevant to understand the effect of a virtualization layer on power consumption and on CPU and memory utilization. Figures 7 & 8 present the effect of an additional virtualization layers on the compute nodes. 'A' denotes that no virtualization is enabled. 'B' denotes the additional virtualization layer enabled by KVM and Openstack components along with Openstack NEAT. No workload is applied on the compute nodes for this experiment. From figures 7 & 8, it is clear that the increase in power consumption, CPU and RAM utilization caused by the virtualization layer is negligible of the order of less than 1 watt and less than 1% of CPU and memory.

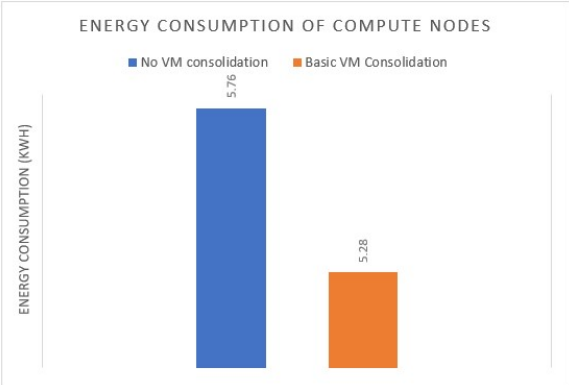

Figure 9. Energy Consumption of Compute Nodes

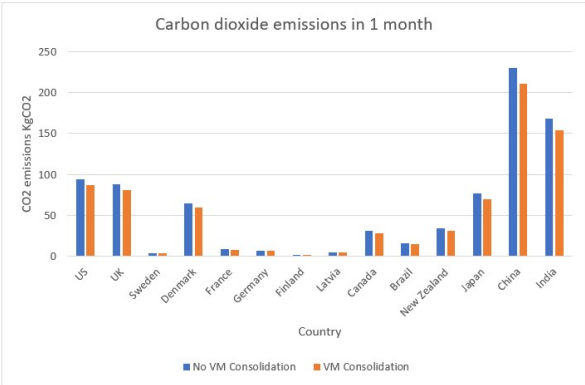

Figure 10. Predicted Carbon dioxide emissions in 1 month

A rudimentary VM consolidation technique was enabled on Openstack NEAT with Threshold Based Heuristic (THR) Algorithm for Underload and Overload detection, Random Choice (RC) VM selection algorithm and Best-fit Decreasing (BFD) algorithm for VM Placement (Abdelsamea *et al.*, 2017). A big data workload as spark jobs was processed on a cluster of virtual machines for 24 hours and compute node energy consumption data was collected. Figure 9 depicts the comparison of the total energy consumed by compute1, 2 and 3 together with and without VM consolidation. Even though the very basic version of VM consolidation technique was used, there is a considerable energy saving.

A basic VM consolidation technique has reduced the energy consumption by 8.33% saving 0.48 kWh of energy in a day. Based on the obtained data, a prediction on carbon dioxide emission for a month in various countries was computed and shown in figure 10. A list of 14 countries which are prime locations of hyperscale datacenters and countries that are suitable locations for data centers were chosen (DatacenterDynamics, 2018) and the carbon emission in KgCO2 for a month was calculated using the data on electricity-specific carbon emission of countries (Brander *et al.*, 2011). There is a significant decrease in the carbon dioxide emission with VM consolidation in each country.

CONCLUSION AND FUTURE WORK

This study has investigated the energy behavior of compute hosts for IoT Big data processing in a cloud infrastructure. The results obtained from real compute resources overcome the drawback of testing VM consolidation on simulated environments with simulated workloads. From a data center perspective, compute hosts and cooling systems are the major consumers of energy. In addition to hardware efficiency and application efficiency, cloud resource management also plays a key role in energy saving. From the preliminary results obtained, power usage characteristics of compute nodes highly vary based on the underlying hardware. Understanding the characteristics and optimizing the usage dynamically is effective. The additional overhead caused by virtualization on the compute hosts in negligible considering the value it brings in. VM consolidation reduces the overall energy consumption thereby reducing the utility and operational costs. It has a great impact on improving the lifetime of the hardware and therefore less electronic waste. It can also play a vital role in countries that generate electricity from fossil fuel thereby reducing the negative impact on the environment by burning lesser non-renewables. This paper aptly falls under the theme 'Green Technologies and IT'. Though VM consolidation benefits cloud infrastructure, it is important to choose the right strategy. An energy-aware system is effective when there is no compromise on performance. Choosing the right strategy for
IoT big data workload considering energy and cost hand in hand will be the future of this research.

ACKNOWLEDGEMENT

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SENSITIVITY ANALYSIS OF ENERGY CONSUMPTION OF INTEGRATED FAÇADE SYSTEMS: SYSTEM AND SUB-SYSTEM VARIABLES OF A BASE CASE MODEL FOR BUILDING ENERGY SIMULATION

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Keywords: Sensitivity analysis, base case model, benchmarking, Building Energy Simulation (BES).

ABSTRACT

Buildings Energy Simulation (BES) has been used as a substitute for more time and cost intensive physical modelling methods such as test cells, environmental chambers and real building monitoring. Their flexibility, ease of use and broader coverage are also very strong advantages they have over mathematical modelling for energy studies. Development of a benchmark model for BES is the first step in this methodology and bares high importance on methodological reliability and validity of the study. This paper uses a unique methodology to develop a base case model as a benchmark model for BES of highly- to fullyglazed office buildings in hot and arid climates to test the robustness of the results of the model developed. Using the base case and the variables at the system and sub-system level – as set out through the methodology developed for this study – the paper will conduct energy simulation of different scenarios and will carry out the sensitivity analysis to test out the robustness of the results. The results form part of the analysis of the research, which has been designed to provide a full account of how different combinations of a set of variables can and will influence energy generation/use, indoor comfort, and daylighting of highly- to fully-glazed office buildings in hot and arid climates.

INTRODUCTION AND BACKGROUND

Integrated Façade Systems (IFS) in which different technological solutions are incorporated to improve the building performance and to lower its environmental impacts can not only offer many positive impacts on the environment but they can also play as a part in more recent strategies for integrated and holistic building design. Better control of heat gain, thereby air-conditioning loads can be administered and glare control while the use of natural light are maximised are some of the advantages of IFSs (Ibraheem et al., 2017). Incorporating High-Performance Glazing (HPG), Shading Devices (SD), and Integrated Photovoltaics (IPV) are some of the most effective strategies in designing IFSs. Despite its growing importance, the research in this area is still relatively limited. It is even more so for non-residential buildings with fully- or highly-glazed façades in hot and arid climates. Moreover, lack of systemic studies on such systems with customisable parametric characteristics which makes them flexible and

accommodating for different geographical, site, building and component factors to suit other contextual conditions indicates a major gap in the knowledge in this specific area.

An established and tested methodology to carry out studies of this nature is building energy simulation (BES). BES provides a reliable, affordable and time efficient alternative to physical mock-ups, and real building testing (Hui, 1998, Anderson, 2014), and is more user-friendly, more agile, more flexible and faster than mathematical modelling. Energy performance of a building can be analysed dynamically through BES to help understand the relationship between the design parameters and energy use in a building. BES is widely used in building performance assessment and design (Ayyad, 2011, Kim et al., 2012, Awadh and Abuhijleh, 2013, Namini et al., 2014, Lamnatou et al., 2015) both by researchers and practitioners.

Various simulation tools can be utilised to predict the energy performance of a building. Crawley et al. (2008) carried out analysis of major BES tools such as BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES-VE, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. The features studied included modelling features, zone loads, building envelope, daylighting and solar gain, infiltration, ventilation and multi-zone airflow, renewable energy systems, electrical systems, HVAC systems, emissions, economic evaluation, climate data availability, results reporting, validation, user interface, links to other programs, and availability. On the other hand, another analysis carried out by Attia et al. (2009) and Attia (2010) used more intuitive ('Architect-friendly') analysis of the BES tools. Both studies ranked IES-VE at the top of their list as a powerful dynamic simulation tool which has been widely used by different researchers (Ayyad, 2011, Kim et al., 2012, El Sherif, 2012, Awadh and Abuhijleh, 2013) just to name a few. Moreover, the modular construct and new capabilities of IES-VE allows for parametrisation of the thermal, day-lighting, artificial-lighting as well as PV generated electricity under one full suite of a software application which ensures consistency, reduces the risk of double-counting and any other discrepancies or problems which may arise as a result of software interoperability issues.

To be able to devise and carry out a systemic study on IFSs using BES, the first step is to develop a base-case scenario; what is also known as a benchmark or a building prototype. It should be flexible and customisable enough to be used as to develop different combinations of the façade components considering the unique set of possibilities and limitations as set within the study. The use of office prototypes dates back to 1990 to investigate the effect of shading devices on energy performance (Leighton and Pinney, 1990), which allows for detailed analysis of energy measures at building scale (Torcellini et al., 2008). Leading research institutions, such as U.S. Department of Energy (DoE), Lawrence Berkeley National Laboratory (LBNL), Pacific Northwest National Laboratory (PNNL), and National Renewable Energy Laboratory (NREL) have developed such models to represent 70% of offices in the United States (EWC, 2012) which have been used to investigate thermal and visual performance of fenestration systems (Haglund, 2010, Carmody, 2004). However, those models cannot be applied to similar studies in other contexts and therefore a contextspecific representative model is always needed in order to represent real practices in a certain context. Development approaches of representative buildings have been devised and applied. A comprehensive review of the literature on developing benchmarks for energy simulation purposes has been carried out by Pomponi and Piroozfar (2015). Earlier attempts used standardised offices to

provide details about the building envelop (Leighton and Pinney, 1990), whereas others focused on grouping benchmarks based on their ventilation type and layout (EEBPP, 2000), or into five categories based on urban context, structure, construction materials, envelope systems or internal layout (Dascalaki and Santamouris, 2002). In places where data or precedent studies are not available or accessible, generating benchmarks could be achieved by conducting a questionnaire survey on buildings in order to realise a prototype model to represent the buildings (Hernandez et al., 2008).

The approach developed for this study builds on comprehensiveness and inclusiveness of a wide variety of parameters where the methodology aims to develop a full parametric combination of such variables. As a result, the complexity of this study grows exponentially and requires a proportionate statistical method to gauge the impact of those changes on output variables. Sensitivity Analysis (SA) helps assess the significance of various input parameters, provides a robust tool to quantify the effect of different design parameters, and can be categorised in different ways (Hamby, 1994, Frey et al., 2003, Tian, 2013, Nguyen and Reiter, 2015). SA have been divided into mathematical approach, statistical (or probabilistic) approach or graphical assessment (Frey et al., 2003), or Local, Global or Screening (Heiselberg et al., 2009). The latter classification is the most commonly adopted in BES studies (See for instance Tian (2013) and Nguyen and Reiter (2015). Others have coupled both Sobol index and Morris's SA method with uncertainty to compensate for input parameters variation where they were not available (Hopfe and Hensen, 2011, McLeod et al., 2013). In the absence of the ranges of variation of input parameters, Latin Hypercube Sampling (LHS) method has also been used to generate the input data variation ranges. Standardized Rank Regression Coefficient (SRRC), by contrast, has been used as a quantitative measure of sensitivity where the data variation range is known. Once the SA is measured and determined, the relationships and the relative importance of design parameters can be understood and the building performance can be improved most effectively and most efficiently by focusing on the more important design parameters. To address this gap, this paper seeks to achieve two different aims:

1. To devise a base-case model to be used as a benchmark and for possible different combinations of parameters to test the impact of change of façade elements on the output variables.
2. To establish and test out a statistical method by which the impact of change of those parameters can be measures and weighed against the others' so that evidence-base decisions can be formulated and design solutions can be proposed using a systemic and comprehensive approach.

RESEARCH DESIGN AND METHODOLOGY

This research utilises a methodology which is derived from modern systems theory and the application of building science to building performance (Kesik, 2014). Others investigated the building envelope as 'the system', the building as 'the super-system' and the façade components as 'the sub-system' to study customisation in AEC industry (Piroozfar, 2008) and for application of BIM to facilitate a fully customisable façade system (Farr et al., 2014). This methodological approach has benefits for both theory and practice. The study of the literature

can be conducted using this methodology in a comprehensive manner. Moreover, this methodology can help classify the impacts of change of parameters at different system levels. It further enables the decision support for design and technical interventions, and practical applications of IFSs. As the first implication of this methodology, the body of literature about PV as shading devices were classified under: performance aspects, assessment methods and design considerations/configurations which are not mutually exclusive (Figure 1). With this vision at its core, this study takes the building level as 'the system'. The upper level, 'the super-system', includes the context in which building exists such as site, geographical location, climate (micro and macro), etc. and the lower level, 'the sub-system', involves the façade and its associated compartments and elements (Figure 2).

This methodological approach has then been used to develop a base case and to determine the variables at the system and sub-system levels as defined in the methodology. To validate and test the base case, energy simulation of different scenarios will be conducted.

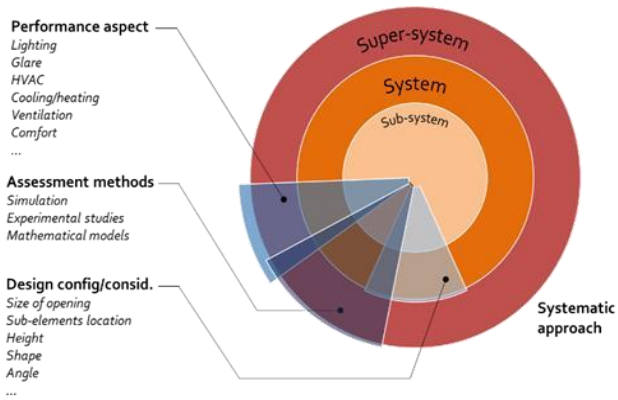

Figure 1: The identified scopes of literature superimposed on the systemic approach

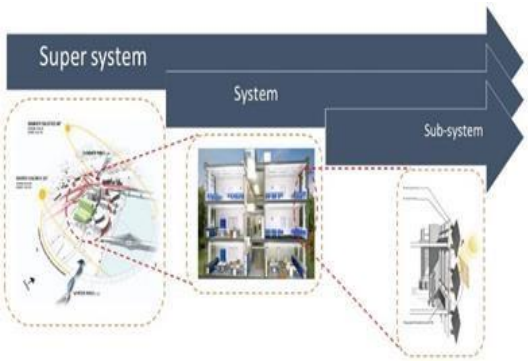

Figure 2: Systemic approach developed and deployed for this research

SA will then be carried out to demonstrate the impact of changes in input variables on output variables e.g. energy generation, energy consumption, and daylighting. In this paper, only energy consumption has been chosen as the representative indicator to demonstrate the sensitivity analysis. The model development will be elaborated on as a part of research instrument development in the data generation section.

In SA, the interdependency of the input and output variables is of paramount importance to ensure that all the variables are taken into account and no variable is unduly represented. Figure 3 demonstrates the interdependency of the variables in this study.

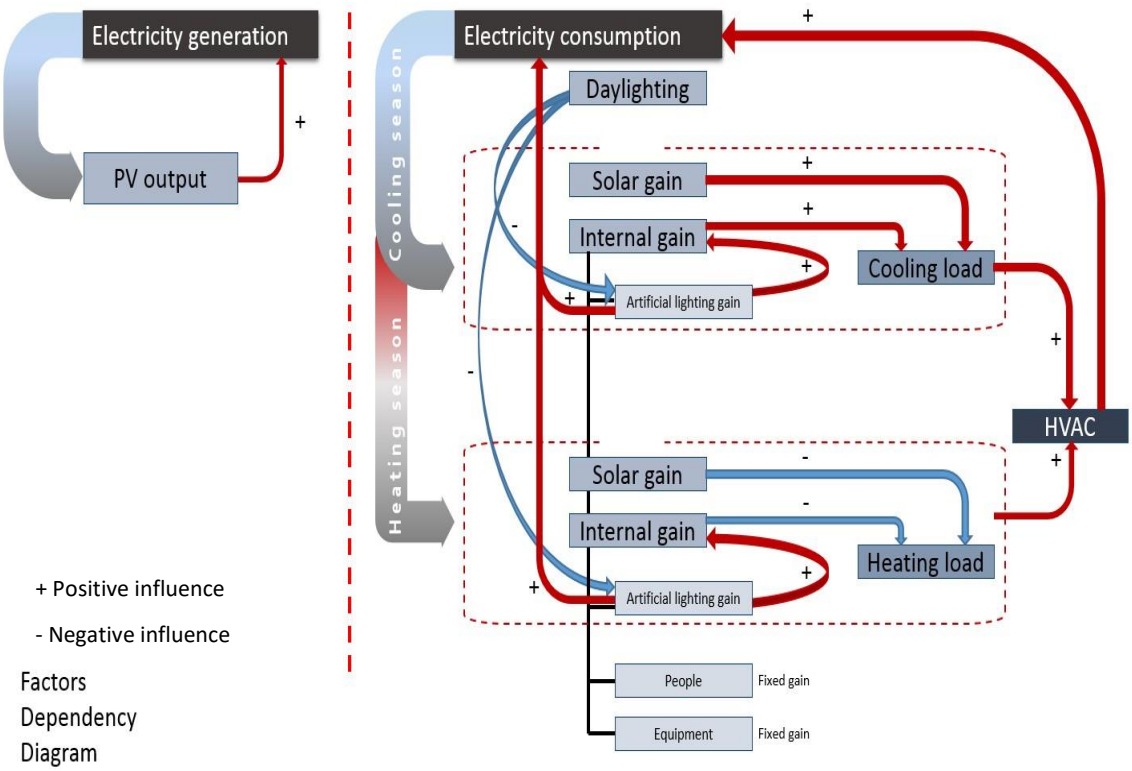

Figure 3: Interdependency of variables

DATA GENERATION

The building is a mid-sized office building with an internal cellular layout, separated by a central hallway of 2.0m wide. Dimensions of each office (or 'thermal zone' in BES) are 4mX6m. The story height is 4m. The built to land plot area ratio is between 40% and 60%. The ground floor layout is sitting back off the edges of land plot unlike the rest of the above floors which fill the layout. The entrance of the building is at the middle of the front façade facing the main street. This model was developed based on the results of a remote survey carried out between Nov 2016 and Feb 2017, distributed via email, social and professional media and local PSRBs to 88 professionals. 72 responses were received and the final number of valid responses was 65, bringing the response rate to 74% due to purposive snowball sampling strategy utilised. The authors' professional experience, expertise and local knowledge were used to develop the initial questionnaire. In addition to the survey outcomes, findings from the literature related to modelling of a representative or benchmark model were also used for the development of the representative model.

Few simplifications had to be applied to the final model in order to increase the accuracy of the intended results of the simulations (Figure 4). This helped eliminate variations that did not have any implications on the thermal performance of the building or where reaching consensus in the survey was not possible, such as the location of the services (wet zones) and the vertical access. The vertical access and the services (wet zones) were not included in the model due to the variation they may have from one design to another. This makes it hard to represent one identical occurrence with any reasonable frequency. Similar

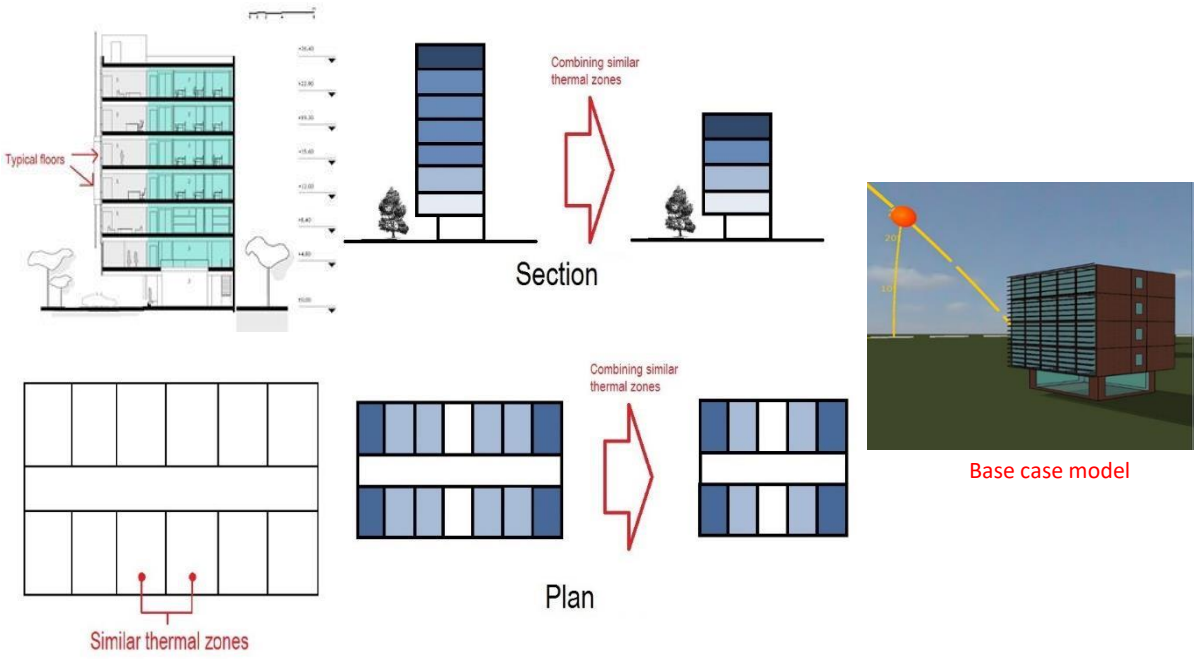

Figure 4: Interdependency of variables

approaches have been utilised for developing benchmark models, by other researchers such as Pomponi and Piroozfar (2015). From the thermal zoning point of view, in the layout, the number of the thermal zone variations should cover all the possible unique zone characteristics to facilitate a comprehensive, accurate and detailed analysis. Therefore, the common practice in building physics is to omit similar zones (vertically and horizontally) to the extent that the model includes only one of each particular thermal zone. Therefore, another round of simplification was made to the model on both the number of the floors and the plan layout.

The model geometry was created in ModelIT-IES. The glazing systems created in LBNL Window 7.5, were imported to APcd-IES to be added to the model. Other construction materials of external walls and internal partitions were set up in APcd-IES. The model uses Baghdad weather file is set up in APLocate-IES for feeding into Apache, Radiance and SunCast. The optical properties of the glazing systems were set up in Radiance-IES. Occupancy profiles, internal gains, HVAC systems, dimming profiles, weekly and daily profiles were also set up in APpro-IES. Subsequently the simulation file is set up to run SunCast for solar shading calculations and Radiance illuminance calculations whose output would then be used to integrate within the thermal calculations in Apache. All simulations are organised in Tasks-IES[1]. Simulations were run in batches on six computers and the results were organised in VistaPro-IES to be used for analysis in Microsoft Excel™. Subsequently a database was prepared for IBM SPSS™ to run sensitivity analysis.

[1] "Tasks-IES" is an IES-VE parallel simulation tool which allows for multiple simulation runs concurrently. It provides a single user interface for displaying and managing all of the user's simulations IES-VE 2017. Parallel Simulations User Guide. Glasgow, UK: Integrated Environmental Solutions Ltd.

DATA ANALYSIS AND RESULTS

The detailed analysis of all the assessment indicators under investigation were conducted in three phases, starting with inferential data analysis as phase one, followed by decisional synopses (phase two) and finally Sensitivity Analysis SA as phase three, which is the main focus of this paper (Figure 5).

Classification of all the variables under investigation was carried out based on the systemic approach. Variables at system level were clustered separately as Orientation and Window to Wall Ratio (WWR). Sub-system variables were clustered into sub-groups. Those are depth of panels, d/l (d=depth of the PVSD and l=distance between the PVSDs), angle of inclination and glazing systems. This is summarised in Figure 6.

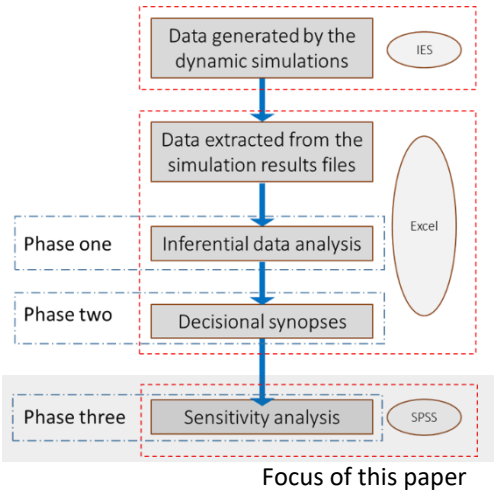

Figure 5: Analysis stages of the study and the focus of this paper

The same steps are followed for each of the output parameter in this phase; starting with energy performance indicators such as electricity consumption, solar gain, artificial lighting gain, cooling load, PV electricity generated, net energy and energy saving, as well as daylight performance indicators i.e. $UDI_{300\text{-}3000\ lux}$ for the daylight sensitivity analysis. In this paper, only electricity consumption will be presented. The data was prepared for the analysis in SPSS by setting up the type of variables. The variable interdependencies were applied. The 'measure level' of each variable was also specified. In this study the independent variables are Nominal variables while the dependent variables are all Scale variables. The input variables represent the predictors for which importance graph is generated. This is calculated to account for the sensitivity of the output when the input variables change, taking into account changing of other inputs at the same time.

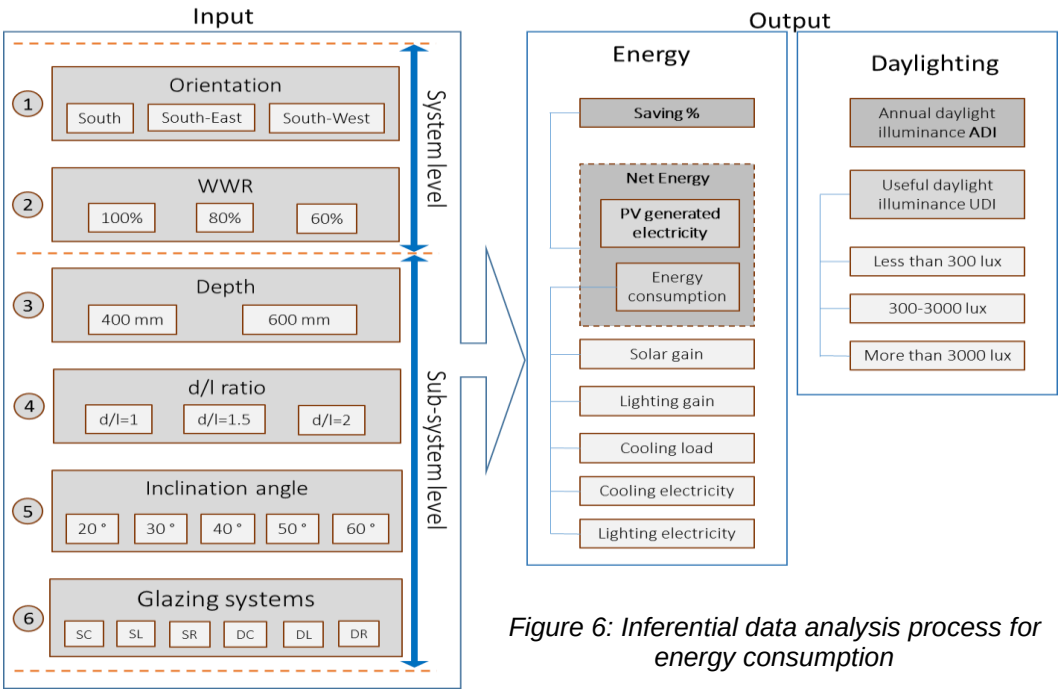

Figure 6: Inferential data analysis process for energy consumption

The predictor importance view is then plotted. This view shows the predictors in the final model in rank order of importance. The results were analysed using a linear regression modelling with 95% confidence interval. For linear models, the importance of a predictor is the residual sum of squares with the predictor removed from the model, normalized so that the importance values sum up to 1 (Norušis, 2012). To check that the assumption of linearity is correct and the model can predict the output, a plot of the predicted results (based on the regression model) vs. observed results (extracted from the simulations) was generated. The closer the scatter plot is to 45°, the more accurate the model will be (Norušis, 2012).

In order to account for the reliability and validity of the models and results in this study, a verification process needs to be followed to ensure that the method of analysis can accurately predict the results and the models are accurate to satisfactory levels. This was followed within the SA by examining the model accuracy which is deemed to be a high-level summary of the model and its fit. The value of the displayed accuracy on the model summary chart is 100 × the adjusted R^2. Models with R^2 of less than 0.5 indicate no better than random occurrences.

Finally, One-At-A-Time (OAAT) analysis of the mean values of variations of each parameter were analysed in order to zoom-in on each of the parameters and to demonstrate the changes that correspond to each of their variations.

The results of energy consumption from all the 1620 dynamic simulation models were analysed in SPSS using a linear regression modelling with 95% confidence interval. Figure 7 shows the predicted vs. observed graph, indicating a high accuracy of the model, verified by the model summary in Figure 8 where the adjusted R^2 coefficient is 0.972. The level of impact of variations in each of the parameters on energy consumption is shown in Figure 9 where the importance of the parameters are quantified and ranked. It is evident that glazing system (HPG) is the most important parameter because its variation has the highest influence on energy consumption figures (more than 80%), followed by d/l ratio in the second place, with significantly lower impact of nearly 13%. The least influential parameters are WWR, angle of inclination and orientation scoring at 3%, 2% and 1% respectively. It can be noted that the depth of the PVSDs has no effect on energy consumption as it did not score in the sensitivity analysis.

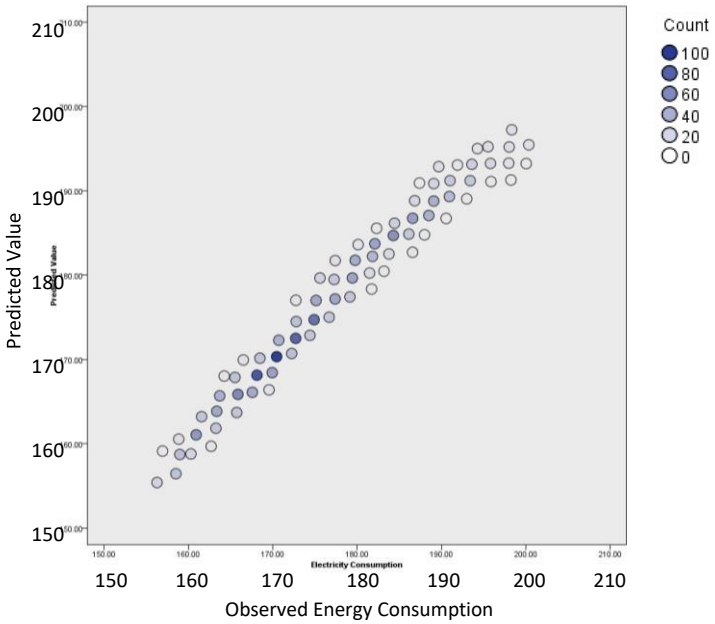

Figure7: Predicted by observed plot

Target	Electricity Consumption
Automatic Data Preparation	On
Model Selection Method	Forward Stepwise
Information Criterion	1,749.854

The information criterion is used to compare to models. Models with smaller information criterion values fit better.

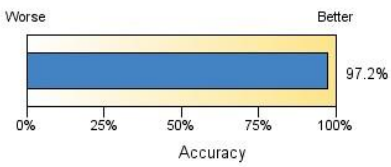

Figure 8: Model Summary

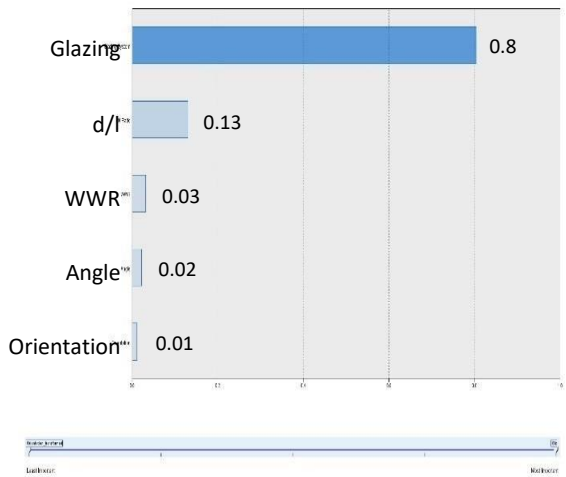

Figure 9: Predictor importance for Electricity Consumption

OAAT graphs of the influence of individual input variables on energy consumption are shown in Figure 10. On the x-axis, the variations of each parameter are plotted with their influence on the energy consumption shown on the y-axis. It can be seen that the depth has negligible

influence where the red line that connects the mean values of the two different depths (400mm and 600mm) is almost horizontal. On the contrary, glazing is extremely influential. This is evident from the fluctuation of the mean values of each type of glazing system. In addition, the figure shows that d/l ratio, followed by angle, WWR and orientation do have some impact but definitely less of influence. The findings of the analysis of the graphs in the figure confirms the findings from the sensitivity analysis.

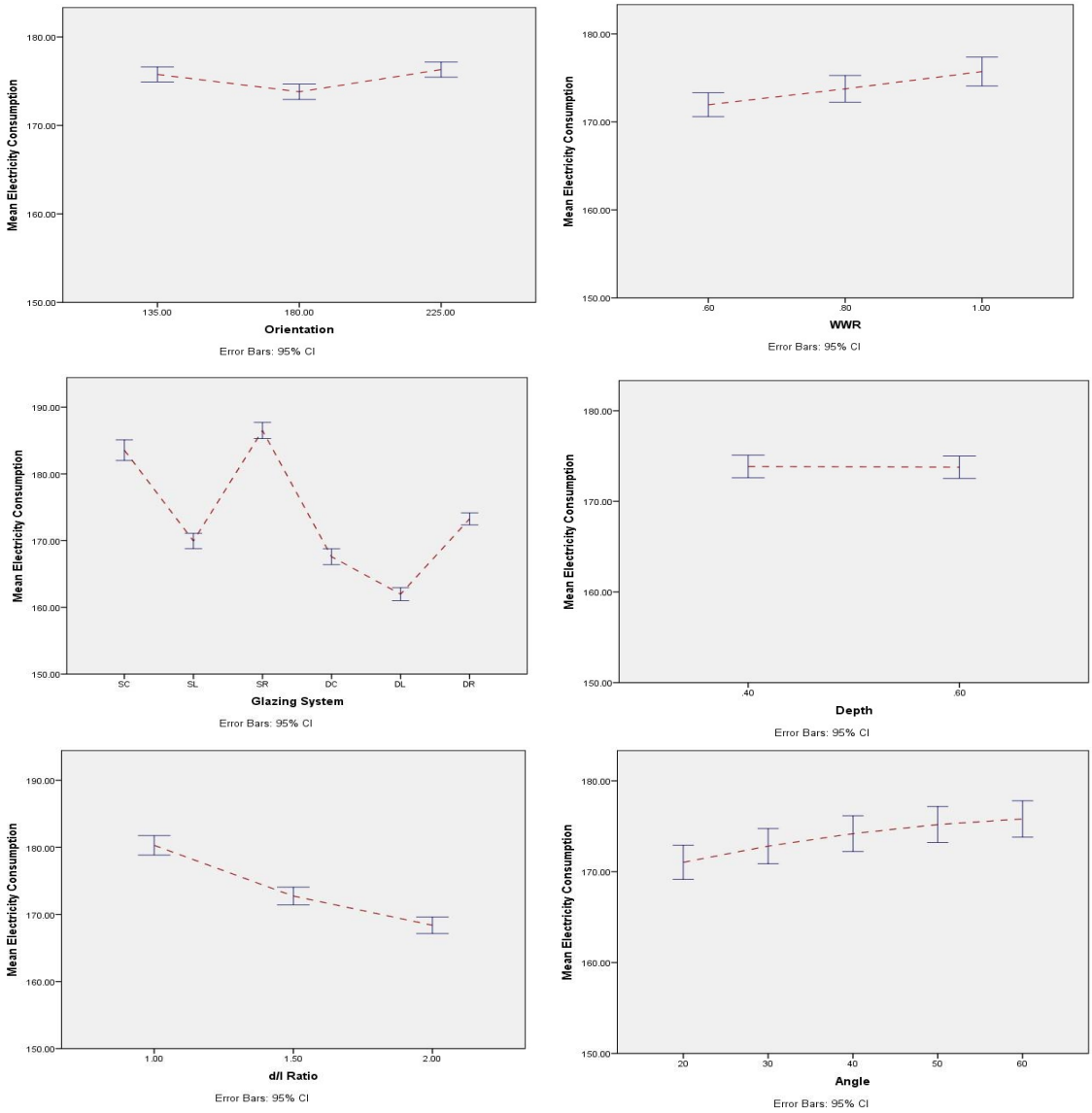

Figure 10: OAAT graphs of the mean values of energy consumption

DISCUSSION OF FINDINGS AND CONCLUSION

Three different building orientations have been investigated in this study: South, South-east and South-west. Combinations at South orientation are less energy intensive compared to those at south-east and south-west. In the sensitivity analysis, orientation was found the least influential variable. For WWR, variations of 60%, 80% and 100% were tested. The trend of the mean electricity consumption shows that the bigger the WWR is, the more energy intensive the combinations are, reflecting a quite significant variation in the range of mean values. The SA

substantiates the fact that WWR is significant in its effect on energy consumption but as a second most impactful parameter. Surely this correlates to the amount of the solar gain and the influence of that on increasing the cooling loads thereby increasing the electricity consumption. The depth has the minimal effect, as the OAAT figure shows that the change of the depth from 400mm to 600mm has a negligible influence on energy consumption. Some previous studies suggest otherwise. For example, Kang et al. (2012) assert that the depth is more effective. Such contradiction could be because that study mainly focused on the electricity generation by PV panels and did not include any other aspects such as cooling loads or daylighting, which can significantly contribute to electricity consumption. The d/l varied from 1, to 1.5 and 2. It was found that the mean value of electricity consumption negatively correlates to the d/l ratio, as shown in OAAT figure, with d/l scoring the second most influential variable on electricity consumption. This is because increasing the distance between the PVSDs will allow for more sun beam to penetrate into building and results in higher solar gains, hence introducing more cooling loads. When examining the angle of inclination for its range of variations (20, 30, 40, 50 and 60), OAAT figure of the mean values of electricity consumption shows a nearly steady increase in the electricity consumption with an increase in the angle of inclination. Although increasing the angle of inclination of the PVSDs reduces the solar gain, it negatively affects the dimming of the internal artificial lights, which in turn, results in additional internal heat gain that contributes to cooling loads, hence an increase in the electricity consumption. In all cases, it was found that 20° seems to be the optimum angle of inclination, but that is only true when the electricity consumption figure was considered on its own. The SA shows that the angle of inclination is the third most influential parameter on electricity consumption. In OAAT analysis of the electricity consumption, the most obvious observation is the wide range of variation of the energy use due to variation of different glazing systems. It also shows that Single-clear (SC) and Single-reflective (SR) are the most energy intensive glazing systems; SC for being the system with the least improved thermal properties and SR for being the system with its unique optical properties. Low-e glazing – both single (SL) and double (DL) – seem to be better choices for energy-efficient purposes than double-clear (DC). Double-low e (DL) shows the most improved combination. The SA of electricity consumption proves that varying the glazing system accounts for 80% of influence on electricity consumption.

It was also shown, with the help of sensitivity analysis, that the effect of alteration of each input variable on energy consumption can be quantified to allow for more accurate decisions to be made for optimum design solutions. Results from the sensitivity analysis show that parameters at sub-system level have a higher influence on the outcome than those at the system level. These results help understand where design efforts should be heading if a successful application of IFS is intended.

The findings of this study conformed to some of the previous research findings. The previous research in this filed seems to be restricted to study of individual components of IFS, missing out an important point which is the overall performance of IFS when the glazing systems, in actual settings, is combined with other elements of the building envelop, such as shading devices, especially when they are integrated with PVSDs. The absence of a holistic, comprehensive study and systemic analysis is one of the major contributions of this study for which this paper laid the foundations by devising an instrument as a witness case to measure

and monitor the impact of change in different input variables on selected output variables; in this case energy consumption of the building.

On the other hand, some findings of this study contradicted previous research findings (e.g. the effect of the depth of PVSDs on energy consumption). This is not unexpected because previous research has had limited scope and has only focused on part of a problem in an actual setting with a deterministic approach to freeze or factor out other influential parameters. By contrast, the research, is unprecedented in its comprehensiveness and its unique methodological approach which is customisable, adaptable and usable in other contextual conditions and has the capability to take full account of parametric combination of all different input variables on a selected output parameter.

This paper highlighted the fact that adopting the systemic approach will help further the understanding of some phenomena and justifies how the contributory elements would behave when combined effects are under investigations.

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USING GREEN WALLS TO HELP REDUCE POLLUTION AND ENERGY CONSUMPTION IN CITIES

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Keywords: Green walls, Energy, Pollution, Sustainability

Abstract

The concept of green walls dates back to the 1930's, but the first modern system with hydroponics was created in 1998 by Patrick Blanc (Land Archs, 2014). Since then, green walls have become increasingly popular around the world, with 80% being constructed after 2009 (greenroofs.com, 2013). There are over 3.5 billion people living in cities today, which is half of the world's population. In 2016 the Sustainable Development Agenda stated that by 2030, nearly 60 percent of the world will live within urban areas (United Nations, 2016). With the clear majority of energy consumption and carbon emissions coming from cities, it is important to combine all the resources available to tackle climate change within urban areas, to really make a difference. This paper investigates green walls to see how they can reduce air pollution and energy consumption. A review of existing literature was used to gain and understand of the theory behind how green walls were able to reduce outdoor air pollution, indoor air pollution and energy consumption. The research then focused on finding examples of case studies and experiments which could prove that green walls could perform in reality. A case study was found which showed that green walls were able to reduce air pollution in an outdoor location with high concentrations of particulate matter, and indicated the plants which were most effective in doing this. There were several experiments on internal green walls which showed the potential that they had in reducing CO_2 from the air but there were no case studies of green walls in practice which showed this. There were positive experiments on external green walls which demonstrated their ability to reduce the temperature of the external wall behind them by up to 20°c which meant energy consumption was reduced significantly. A year-long study in the UK proved that they were also successful in insulating the building which meant they could help the thermal performance throughout the year. To show how green walls could be advanced for the future, a short study was included on a green wall that has the ability to create electricity.

INTRODUCTION

Air pollution and energy consumption created from non-renewable resources negatively affects our quality of life and health conditions (Borhan et al., 2011). An estimated 6.5 million deaths are associated with air pollution every year and its believed that 92% of people worldwide do not breath clean air (World Health Organisation, 2016). Although some air pollution is caused naturally, man is responsible for most of the world's air pollution, both indoors and outdoors (Orwell, 2017). Man-made air pollution is a direct result of people using energy by, for example, burning fossil fuels and driving cars. What is being done to mitigate the problem? Examples of strategies already in place include: The transport industry, where

more people are choosing to cycle instead of using their car or public transport. Car manufacturers are slowly switching from petrol and diesel-powered cars, to cleaner hybrid and electric cars. Cities are being designed to be more compact by building up instead of spreading out over a larger area thus making them more efficient. There is also an increasing use of low emission fuels and renewable energy such as solar or wind power (World Health Organisation, 2016). To make a considerable difference, people must contribute from all methods that are available. One of them is green walls. As well as green walls being aesthetically pleasing, they can help in reducing air pollution, moderating local climates, improving energy efficiency, improving work ethic and providing biodiversity habitats (Staffordshire University, 2015). Taking into account these facts, this paper will explore the evidence there is that green walls can help in reducing air pollution and energy consumption in cities and ways in which they could advance in the future.

RESEARCH REVIEW AND METHODOLOGY

Reviews of existing literature will be the primary source of research for this paper. Qualitative data is exploratory research which is used to develop an awareness of people's thoughts and opinions. This will be explored and analysed to provide the reader with an understanding of the theory behind green walls and what their benefits claim to be. In addition to this, secondary quantitative data will be gathered and reviewed to back up the alleged benefits. Quantitative research is numerical data, such as graphs and statistics which is used to formulate facts (DeFranzo, 2017). The findings will then be discussed, and a conclusion will be made about how beneficial green walls can be.

Research method

A background of the history of green walls and the types of green walls available will be used to introduce the subject and give the following research context. Each of the described benefits will then be explored and the theory behind each will be presented to the reader. Using case studies, information and data collected during the research, the theory behind each benefit will be backed up by numerical data that has been gained from existing experiments.

Background

The original concept of green walls can be traced back centuries to the Hanging Gardens of Babylon, one of the seven ancient wonders of the worlds. This tradition was carried on in hot climate countries where different climbing plant species are grown along the building envelope to shade the façade from too much sun exposure. They were further used in medieval Europe to grow fruit and vegetables in limited horizontal space (Wood, Bahrami and Safarik, 2015). In the 1920's the British and 'North American Garden City Movement' promoted pergolas, trellis structures and self-climbing plants. It was in 1988 that Patrick Blanc introduced the first stainless steel cable system which allowed more sophisticated designs and by the 1990's wire rope net systems and modular trellis panel systems were invented. (Hopkins and Goodwin, 2011). A green façade refers to a system where self-climbing plants grow from the ground, usually up a trellis and cling to the wall or a cable and rope system that keeps it away from the

wall to prevent damage (Hopkins and Goodwin, 2011). Green walls, which can also be referred to as living walls or vertical gardens differ as they use a system where plants are integrated into the façade construction in which plant and plant media are both placed on the vertical surface of the exterior wall (Wood, Bahrami and Safarik, 2015). Green walls can be hydroponic or soil based. The first consists of two layers of fabric with pockets filled with the pre-grown plants and growing media. The fabric walls are supported on a framework and backed by a waterproof membrane against the building wall. Water and nutrients are delivered through an irrigation system at the top of the wall (Agritech, 2017). The latter system uses metal boxes or trays which are filled with the growing medium, these are planted then hung vertically on the support system. These can often by a lot heavier and the size of the box restricts how far the roots can grow. These also use an integrated irrigation system to provide the plants with nutrients and water (Greenovergrey.com, 2017).

The type of green wall and the plant species chosen will be based on the environment that it is situated, some buildings may not be able to take the weight of a particular system or be able to take the weather conditions, such as the wind load on the building.

Reducing outdoor air pollution

There are many different pollutants in the air which can affect our health, but in cities transportation is causing the majority of the air pollution by releasing carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter (Veetil, 2012). In addition to these pollutants being released into the air, they are then trapped in, by what is known as an 'urban street canyon'. An urban street canyon is a place where a street has tall buildings on both sides creating a canyon-like environment (Vardoulakis et al, 2003). Some air pollutants can't escape because winds that enter the urban canyon can create a vortex which then re circulate the wind back down onto the street level and sweep the pollutants from cars etc. up against the side of buildings (Hester, 2009). The rates that they are deposited onto surfaces vary depending on the nature of the surface; deposition rates to vegetation are much higher than those to hard, built surfaces (Pugh et al., 2012). We know that during photosynthesis plants take in carbon dioxide and produce oxygen, but plants also clean the air by removing nitrogen dioxide and microscopic particulate matter (Pugh et al., 2012), so when these harmful pollutants are deposited onto a green wall, they are absorbed by the plants.

What experiments have been done to prove this? It was thought that deposition to vegetation would only make up to a 5% improvement to air quality in urban areas, but a more recent study carried out by (Pugh et al., 2012) which took into account the urban street canyon effect, estimated that street level concentrations of nitrogen dioxide could be reduced by up to 40% and particulate matter reduced by 60% due to the enhanced time that the air stays in the street canyon (Figure 1). The researchers used a computer model that created a virtual green wall in an urban street environment and it captured the trapping of air. They also used the model to distinguish the effects of vegetation in street canyons from those in parks or on green roofs. Green walls were the winners in terms of pollutant removal (Birmingham.ac.uk, 2012).

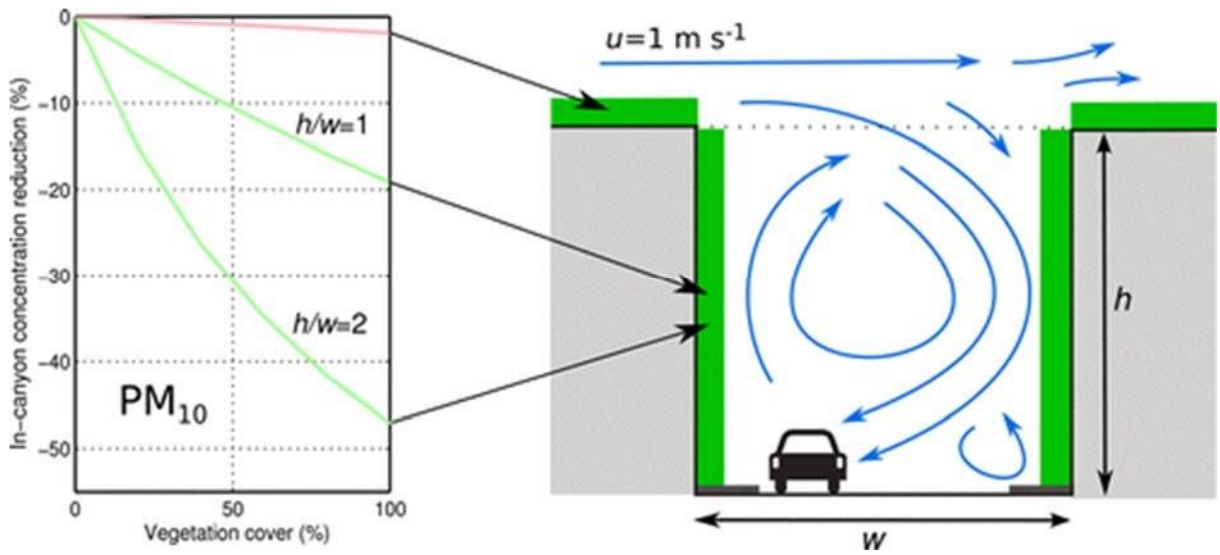

Figure 1. Graph displaying the results of the experiment which shows a correlation between the reduction of particulate matter concentration and the coverage of vegetation (Pugh et al., 2012)

However, as this test is only a computer model, it still does not prove what would happen in reality. One of the reasons computer models are used is due to the number of variables there are which could influence the study. As summarised by (Hester, 2009), the levels of air pollution in different parts of a city are completely different depending on where it is. Influenced by the traffic, the size of the buildings on the street, the location of the building on the street and the weather.

In 2011 a green wall was installed at Edgeware tube station in London as it was an area with high levels of particulate matter in the air. 15 different species of plants were chosen based on their ability to trap a certain type of particulate matter (PM_{10}) which is emitted from diesel engines (The Green Wall of Edgware Road, 2017). Researchers from the Imperial College of London collected leaf samples for 9 months after it was installed to test them and monitor the capabilities that the plants had in purifying the air. There was a great difference in the performance of each species and it was found that the smaller, hairy leaves had a greater ability to trap the pollutants. The Convulvulus cneorum shrub species made the greatest impact. Over the test period the green wall captured 515g of PM_{10}. Although the green wall did help, it was deemed that overall vegetation has only a small effect on reducing PM_{10} in the atmosphere but should still be used as an additionally to other methods in removing particulates from the air (Smith, 2011). Mark Lawrence who designed the wall felt that the test period carried out by the college was not sufficient in gathering the best results (Lawrence, 2013). This was due to no funding to commission further research into the project (Transport for London, 2012).

Reducing indoor air pollution

As well as outdoor air pollution, indoor air quality can be detrimental to people's health and even more so as most people spend from 80-90% of their day in an indoor environment where pollutant levels can be higher (Pluschke, 2004). These types of pollutants can come from mould, tobacco smoke, household products, carbon monoxide and many more

(Medlineplus.gov, 2017). Volatile Organic Compounds (VOC's) are air pollutants which are found at high concentrations indoors as they are emitted from everyday items such as furniture, electrical equipment, perfumes, carpets and paint to name a few (staffs.ac.uk, n.d). The most common of the VOC's are xylene, benzene, formaldehyde, toluene and trichloroethylene (ANS global, 2017). Breathing in these pollutants can cause something known as 'sick building syndrome'. Symptoms of this include, irritated eyes, fatigue, headaches, dizziness and nausea (US EPA, 2017). People often feel better as soon as they remove the source of the pollution. Nevertheless, some pollutants can cause diseases that show up later in life, such as respiratory diseases or cancer (Medlineplus.gov, 2017).

Initially research into this began in the 1980's when new regulations introduced in the United States meant that buildings had to become more airtight. This lead to sick building syndrome starting to occur in offices, so in 1989 a study by NASA (Wolverten et al, 1989) was carried out in a controlled environment whereby various vegetation was used to remove VOC's from the air. They used common house hold plants that were readily available to the public and found that some made a greater impact than others. In a 24 hour period, English Ivy was able to remove 89% of the benzene from the air and the peace lily was able to remove 23% of the trichloroethylene. But it was also found that microorganisms in the plant root soil were effective in removing VOC's from the air (Wolverten et al, 1989).

More recently (Rivera, 2014) conducted an experiment which studied the effectiveness living walls had in reducing carbon dioxide concentration levels indoors. Data was collected from the type of living wall, the plants species and the CO_2 concentration levels from the subject building. This was then input into a computer model and the results showed that CO_2 was reduced by 56%. The study also suggests that lower mechanical airflow rates may further reduce CO_2 levels, but additional experiments would have to be carried out to confirm this.

A study on an active green wall by (Torpy et al., 2016) was carried out to assess the reduction of CO_2 in a test room. They found that increasing the light intensity significantly increased the green walls ability to reduce CO_2 concentrations. The findings indicated that a $5m^2$ green wall of the plant species used could balance respiratory emissions of a full-time occupant (Torpy et al., 2016).

Reducing energy consumption

In hot climates, buildings heat up due to solar radiation, which means they then need to be cooled down mechanically, using up large amounts of energy. Some materials can do a better job than others in keeping the building cool. For example, concrete absorbs heat in the day and releases it at night due to its high thermal mass (Yourhome.gov.au, 2013). Unfortunately, in a city where there is lots of concrete and little vegetation, this can bring a negative outcome. It results in cities being much hotter than the surrounding countryside, which is known as the Urban Heat Island effect (Met office, 2012). An environmentally friendly solution could be to use green walls which provide natural shading on buildings. Living wall manufacturers (Sempergreen, n.d) state that plants can absorb 50% of the sunlight they receive and reflect a further 30% which in turn means that for indoor climates 33% less air conditioning is required. They can also serve as an extra layer of insulation due to the stagnant air and the planting medium that exists between the green wall and the building (Zia, Zia and Norouzi Larki, 2013),

so as well as green walls keeping the building cool, they allow the building to retain heat in colder climates due to their insulative properties, making further energy savings on heating. Another way in which green walls can keep a building cool is through the process of evapotranspiration (Heffernan, 2017).

An experiment carried out in Spain, published in 2017 by (Coma et al., 2017) looked into the thermal performance of a green façade and a green wall on two different cubicles, which were built to resemble a house and a third cubicle which was left bare was used as a comparison. The green facade used deciduous creeper plants and the green wall used an evergreen species. They were tested through heating and cooling periods where heat pumps were used to maintain the internal temperature during the test. The electrical consumption of the heating, ventilation and air conditioning was recorded throughout the study. It was found (Figure 2) that the cubicle with the green wall was able to make energy savings of 59% compared to the bare wall. The green façade achieved 33% for the same period. The energy savings weren't as effective during the night, but the cubicle with bare walls still used more energy to cool it down as heat was being radiated into the room throughout the night. The temperature reduction of the outside wall surface of the green façade was between 7-12 ºC whereas the green wall achieved up to 17 ºC.

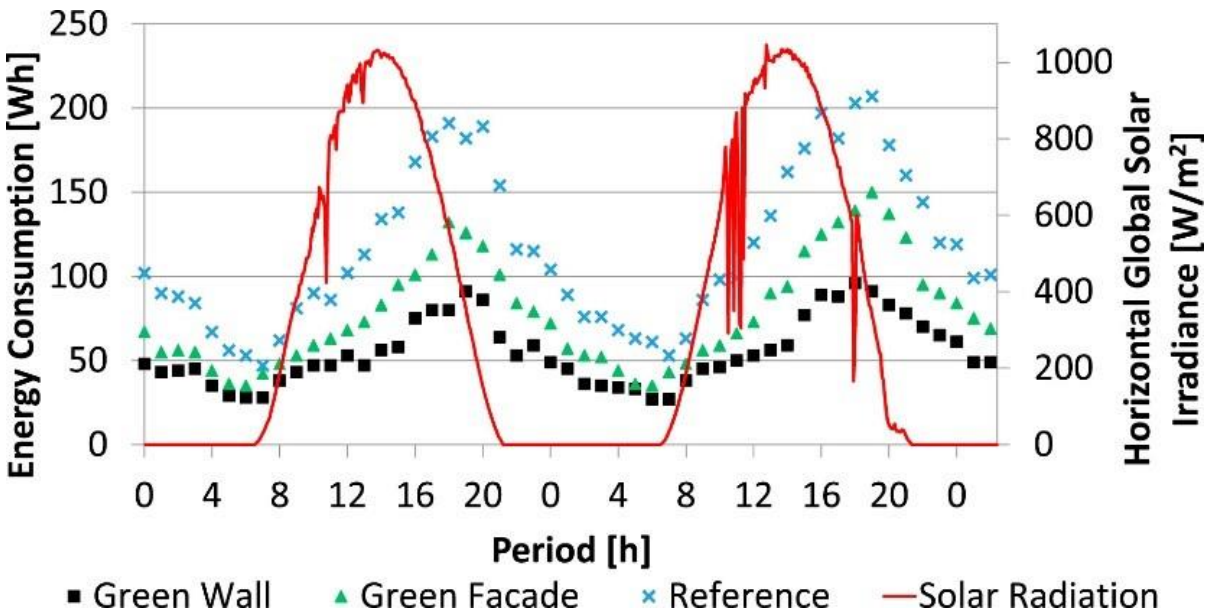

Figure 2. Graph showing the comparison of energy consumption over the test period. (Coma et al., 2017)

The University of Sheffield started a year-long study in 2012 which placed 5 different green wall systems on the exterior of one of their buildings to test the thermal benefits of them. During the summer the external walls without the system on reached 45 ºC but the wall behind the best system managed to reduce in temperature by 20 ºC. During the winter the wall temperature behind the systems with plants was 4-7 ºC higher than the wall with no system which meant that the plants did provide insulation (Scotscape, 2017).

Can green walls produce energy?

Instead of green walls just reducing the energy consumption that is used by buildings, what if they could contribute clean energy to help power it? Researchers at the University of Cambridge have developed a green wall that can actually create energy. The prototype has been developed between scientists and eco-companies. The structure that the green wall is assembled on is a wooden hub that is designed to resemble a bus shelter, with the hope that one day it could power things such as lighting in the bus shelters (University of Cambridge, 2015).

The green walls have been adapted so that they can harvest electrons which are produced naturally as a by-product of photosynthesis and metabolic activity, and turn them into an electrical current (University of Cambridge, 2015). Because the plants generate the electricity from photosynthesis and metabolic activity, it works during the day and at night. The green wall used is a modular system where plants are grown in pockets of soil. This creation differs from normal green walls as the pockets are lined with carbon fibre which receives the electrons. An internal circuit is created in the pockets of soil which allows the electrical current to be transferred to an external circuit and this can then be used as power (University of Cambridge, 2015).

DISCUSSION

The initial research around the subject brought up plenty of information about the advantages that green walls can offer. This lead to looking further into each of the benefits where there was a lot of literature informing the reader of how green walls work. However, after researching many books, journals and webpages it seemed there was more theory based experiments than actual case studies of green walls that could provide quantifiable data.

Firstly, when exploring how green walls could reduce outdoor air pollution, the results were scarce in terms of numerical data that could prove that a green wall was performing well in an urban environment. The experiment by (Pugh et al., 2012) was good news for green walls in terms of what they could achieve. The model showing results of up to 60% particulate matter reduction lead the investigation to try and find a case study where they could prove that these statistics could be achieved. The study into the green wall at Edgeware tube station provided the best results from the research as it obtained numerical data from a case study. It also was able to identify which was the best plant species in removing PM meaning this species could be used more in future green walls. Unfortunately, the research period was short and no further study was carried out, but it was encouraging to establish which plants worked best. It could be concluded that one of the reasons there are not many other studies is due to lack of funding for research, as it was shown in the Edgeware tube station project.

The effectiveness of the green wall could be completely different from one location to another when in outdoor conditions, as there are too many variables, it would be impossible to say that a green wall would perform in a certain way until each one was tested individually which is unrealistic. This could be another reason there are not many case studies on them.

The next part of the study focused on indoor air pollution. There was an abundant supply of literature which explained the effects that indoor air pollution could have on people's health and many articles focused in particular on VOC's. The historical test conducted by NASA which

found the species of plants that could remove the most VOC's from the air, still stands valid today and is mentioned in most literature about the subject. The results of this test were the basis for people keeping plants in their homes to purify the air and is one of the main arguments for having a green wall indoors. Although it should be observed that it was also the microorganisms in the soil which were responsible for removing some of the VOC's in the air, this would mean that a soil based living wall would be the best solution indoors. Green walls also have the added benefit of taking up less floor space than potted plants which is important in offices where floor space costs money.

The (Rivera, 2014) experiment was another computer model based study which used data collected from the building and showed that the living wall would be successful in removing 56% CO_2 from the air. It would have been interesting to compare the results of this to a case study on the same living wall in reality to see if they matched.

The study by (Torpy et al., 2016) demonstrated that the intensity of light on the plants made a large difference to the CO_2 reduction. This test was important because this would not have been realised from inputting data into a computer model. Showing that studies on real green walls are crucial to determine the best conditions for them.

Moving on from air pollution, the next aim of the study was to find out whether green walls can help in reducing energy consumption. Reviews of literature found that there are several ways in which green walls are able to do this. By shading, insulating and from evapotranspiration. The study that was carried out by (Coma et al., 2017) showed that the shading aspect of the green wall was the most effective in reducing energy costs. This test proved that green walls are capable of reducing energy consumption significantly. However, this experiment was carried out in the hot climate of Spain which meant that it was not able to truly demonstrate how well the green wall performed as insulation in colder weather. The study by the University of Sheffield provided positive results of a green wall throughout a comprehensive year-long experiment in a colder climate, something which research was lacking in. This meant that green walls could be effective in colder climates and is a good example of quantifiable data that could be used to prove this.

The final aspect explored the direction that green walls could lead in the future in terms of energy savings. The research from University of Cambridge provided an interesting insight into the capabilities of plants. The fact that the research team were able to harvest electricity from the green wall shows that technology is progressing in this field. Although it was only a small amount now, time will tell how far it can go and hopefully it should inspire more people to research into this topic.

CONCLUSION

There are many known advantages to green walls, but this study focused on their ability to reduce air pollution and energy consumption. The research found that there was a large quantity of literature that explained the theory of how green walls work. However, in comparison there was not as many case studies to prove this. This may be due to the lack of funding, or the time it takes to carry out a comprehensive study on a green wall. Another factor could be that there are many variables that could influence the tests on external green walls

and it would be difficult to provide conclusive outcome which applies to more than one green wall. Overall it could be concluded that from the information that is available, that green walls can be successful in reducing a small amount of out outdoor air pollution, but more studies need to be carried out in a variety of places to see how they perform. For indoor green walls to be most effective they should be soil based to benefit from the microorganisms removing VOC's. Energy savings on mechanical heating and ventilation have been the best outcome of this study, the case studies proved how well the green walls worked both in summer and winter and was an excellent example of the benefits they can offer. In regard to the future of green walls producing their own energy, it may or may not lead to a significant source of energy but even enough energy to power themselves would make a contribution to energy savings.

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AN INVESTIGATION INTO THE ENERGY PERFORMANCE OF SCHOOL BUILDINGS REFURBISHED THROUGH SALIX FUNDING

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Keywords: BIM, refurbishment, energy performance and existing school buildings.

Abstract

Schools in the UK are part of the existing stock of buildings whose operational carbon must be reduced for the government to meet its objective of reducing carbon emissions by up to 80% of their 1990 levels by 2050. State funding for refurbishment is the most feasible option for public schools using two routes: Condition Improvement Fund (CIF) which is restricted to improving the physical aspects (e.g. expansion) of school facilities; and the Salix Energy Efficiency Fund (SEEF) aimed at energy/equipment retrofit measures. Although the use of BIM technology (underpinned by the government softlanding (GSL) framework) as well as the use of energy modelling and simulation tools have become integral to making buildings more energy efficient, they are constrained by lack of adoption. This study used a mixed-method approach to investigate the effectiveness of contemporary BIM and energy simulation technologies in refurbishment of existing school buildings. Secondary quantitative data collected from 10 case studies of schools that benefitted from SEEF was supported by interviews of seven heads of schools that had undergone SEEF refurbishment. Results showed that: CIF and SEEF which administratively are mutually exclusive funding streams ought to operate in synergy due to the interaction of a building's physical envelope with heat transfer and energy used by equipment and systems; some schools are not getting technical advice on how to optimise the funds they receive from SEEF leading to non-optimal investment. Recommendations provided include: extensive training on BIM and GSL to heads of schools and advise to government agencies to reconcile the purpose of CIF and SEEF for a holistic solution to carbon reduction in schools.

INTRODUCTION

Globally, buildings are acknowledged in most countries as contributing up to 40% of carbon emitted (IEA, 2010). As part of its wider sustainability targets and legally binding framework, the UK Government has committed to getting existing to reduce their carbon emission by up to 80% of their 1990 levels by the year 2050 (DECC, 2008) and non-domestic buildings in the UK account for 18% of emissions (HM Government, 2010). It has been acknowledged that retrofitting of buildings will be central to the success of this ambition and for non-residential buildings, e.g. commercial buildings, the energy retrofit market is worth up to £9.7 billion which can be spent on matters like optimised lighting, improved building energy management and control systems (BMCS) and more efficient building services (Dixon, et al. 2014). However, the advent of BIM has meant that consideration must be given for accessing building designs via BIM's object-oriented models. Therefore, this means that the efforts to close the so called "performance gap" need to be compatible with BIM – including the provisions of the BIM-

driven government soft landings (GSL) and there have been studies which have considered these possibilities such as Tuohy and Murphy (2014) and Kelly et al. (2013). Whereas many existing school buildings would not have been procured using BIM processes or technologies, it is likely that refurbishment and expansion projects on such schools can and should benefit from the use of BIM particularly because BIM was mandated for public sector projects. Since the government's BIM mandate was aimed at public sector projects (for which state schools belong) and because schools are responsible for up to 2% of total carbon emitted in the UK, there is a lot at stake in their performance. Investigating the use of BIM as an effective process for assessing energy performance of school (or other types of) buildings requires an understanding of the BIM process and the underpinning technologies. In this regard, the aim of this research is to investigate the effectiveness of contemporary BIM technologies for assessing the energy performance of existing school buildings. The objective of this paper are: (a) to explore the contemporary issues that shape energy performance of existing schools, including the technologies and funding schemes that support their low carbon performance; (b) to examine the energy performance indicators that are used in post-occupancy evaluation of school buildings and to map these with technologies used in BIM process and their suitability for assessing such school buildings; (c) to evaluate the suitability of BIM processes to meet the post-occupancy energy assessment needs of existing school buildings, particularly in view of Government Soft Landings for Level 2 BIM.

LITERATURE REVIEW

Sustainable buildings, BIM and the government soft landings (GSL)

According to Peace, et al (2012), the construction industry is a major employer and accounts for around 7% of the gross domestic product (GDP) of most countries. However, this sector's importance is often tainted by the extensive use of natural resources, particularly the raw materials used in constructing buildings and the energy required to keep such buildings liveable, based on acceptable indoor environmental quality. Hence, the major cost associated with buildings is the operational cost incurred at the post-occupancy stage. It was in view of this realisation that the UK government has led the world in instituting a Government Soft Landings (GSL) policy (Tuohy and Murphy, 2014). This policy requires a follow up and aftercare services led by the designers and contractors and occurs within a mandatory three-year post occupancy evaluation (POE) phase as part of the mandated BIM strategy. In other words, the GSL strategy is a unique framework that binds BIM to the principles of social, economic and environmental aspects of sustainability. The GSL strategy is expected to provide feedback that is actionable for the benefit of owners, users and managers, as well as those who provide heating and energy services to buildings so that during refurbishments or future designs, improvements can be made. It can therefore be deduced that the GSL can help designers and builders close the so-called energy performance gap by validating, fine tuning and debugging the energy systems. This gap represents the mismatch between predicted energy consumption and actual energy consumption of most buildings (Tuohy and Murphy, 2014; De Wilde, 2014; and Johnston, et al. 2015). The use of sensors and smart devices are currently helping in this regard, by making possible a cyber-physical system (Anumba et al. 2010 and Akanmu, et al.

2013) that enables physical data collected from real-time building use to be mapped into digital models for the purpose of analysis.

As mentioned earlier existing buildings contribute significantly to the emitted carbon that is attributed to global warming. The design, construction and operation of these buildings have therefore not been carried out using low-carbon or sustainable processes and principles. Therefore, the best way to reduce their operational carbon is through refurbishment, repair or maintenance of existing fabric or installed systems. These intervention processes provide opportunities to revisit the use of unsustainable construction materials, e.g. those with high embodied energy/carbon or poor insulation as well as equipment which consume too much energy or those that emit greenhouse gases. Additionally, the spatial design of those buildings can also be reviewed and improved during refurbishment so that defects and inefficient performances can be detected and remediated. In this regard, Dong, et al. (2014) conducted a study where they developed a methodology for diagnostics and detecting faults in existing building can be done by integrating real-time data collected by energy management systems with as-built 3D BIM models. The data incudes heat loss and heat gain across the building fabric. Other studies that have looked at energy diagnosis in buildings have investigated the impact of their age and environmental conditions (Golparvar-Fard and Ham 2013) including fault detection through the use of thermal imaging data that is integrated into gbXML models that are compatible with BIM (Ham and Golparvar-Fard, 2014).

However, other kinds of data that can be used in such a cyber-physical system include occupant movement data (obtained from sensors) which can reveal actual behavioural issues with building use, which could provide more accurate picture of energy use than predicted from simulations (Palmer and Cooper, 2012). This is an important point because even though most energy efficient retrofit measures are related to building envelope and insulation (Shorrock, et al. 2005) the behaviour of people in buildings affects heat loss/gain (Kane, et al. 2011) e.g. opening of doors, leaving electric appliances on (Palmer and Cooper, 2012). Therefore, behavioural aspects of occupants can be said to be an important key and clue about why there is performance gap in constructed buildings. In short, refurbishment is an ideal opportunity to look forensically at a building's energy performance for the purpose of closing any gaps and providing economically, socially and environmentally sustainable buildings. It is noteworthy that the data fed into (and exchanged between) BIM software are mostly about geometry, as evidenced by the gbXML and IFC file formats. However, the review of diagnostic investigations into energy use in buildings (Bahar, et al, 2013) suggests that other formats of data, e.g. thermographic images of heat losses; motion of occupants as captured by sensors; etc, are not supported by such BIM tools. These data are crucial to actual energy utilisation and capturing them can only help close the performance gap. With respect to schools, studies such as Burman, et al. (2014) have shown that actual consumption is much higher than theoretical calculations and simulations. They proposed a plan that requires "measurement and verification" for comparing the theoretical with actual performance so that a reliable process for closing the performance gap can be achieved.

Building Energy and Carbon Management in UK Schools

Kilpatrick, et al. (2011) who reviewed the consumption of energy in school buildings with Scotland, argued that it is only by energy data collection and analysis that an understanding of

energy use can be achieved. According to them, the UK is among a minority of countries that have set a benchmark for energy consumption in schools and the target of 110kWh/m²/year is regarded as a reasonable target (Hernandez, et al. 2008). The "Good Practice Guide 343 (or GPG343) has set out good practice benchmarks which include: 191kWh/m²/year for primary schools and 196kWh/m²/year for a secondary school without a swimming pool (Carbon Trust 2003). A recent breakdown of a typical UK School's energy use by the Carbon Trust (2012) shows that space heating accounts for 58% and is allocated around 45% of costs. In view of the importance of schools to the carbon reduction strategy, a consultation paper was developed by the Department for Children, Schools and Families in 2009 (DCSF, 2009). Although schools only accounted for 2% of the total greenhouse gases emitted in the UK, by context this is equivalent to the amount produced from energy and transport by the cities of Manchester and Birmingham combined (DCSF, 2009). The consultation report produced some interesting information about how schools in England contributed to the CO2 emissions by summarising their carbon footprints (Fig. 1). One of the key findings from the study was that modelling results suggested that without active intervention to mitigate the carbon footprints from such schools, the carbon emitted from such schools will remain at their levels up to the year 2050.

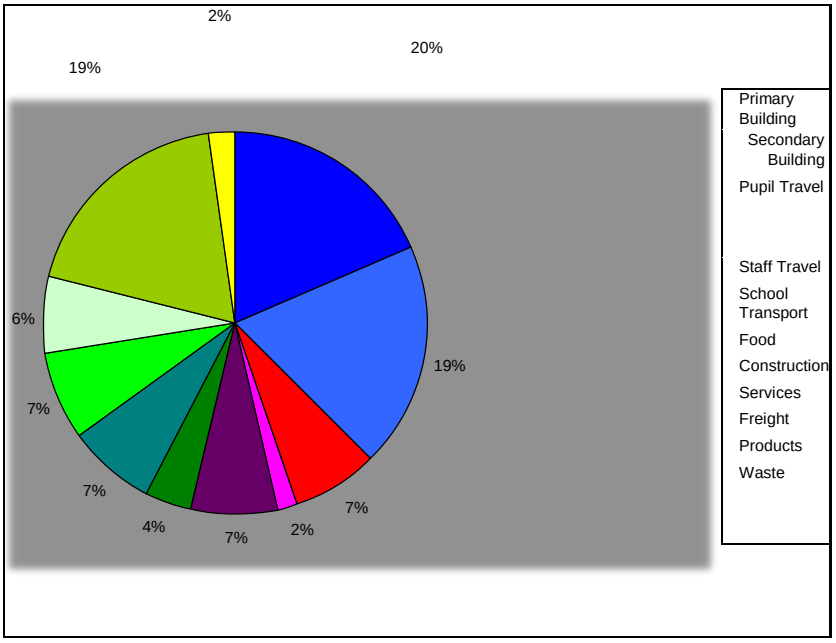


Figure 1: A sector breakdown of schools' carbon footprint in England (DCSF, 2009).

Although this finding from the DCSF consultation paper has contributed to active measures being taken to assist schools[1], it should be borne in mind that there is a performance gap linked to modelling and simulation. This suggests that the data concerning primary and secondary school buildings (Fig. 2) might be under or overestimated. Nevertheless, the data suggests that if business as usual (BAU) is allowed to persist, the UK will not meet its 80% reduction of carbon emissions to the 1990 levels by the year 2050.

[1] Such interventions include Condition Improvement Fund (CIF) and Salix Energy Efficiency Fund (SEEF). See next section.

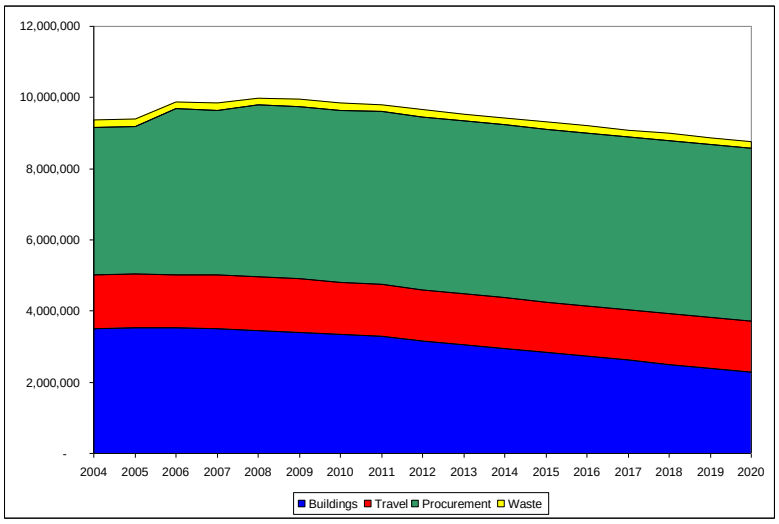
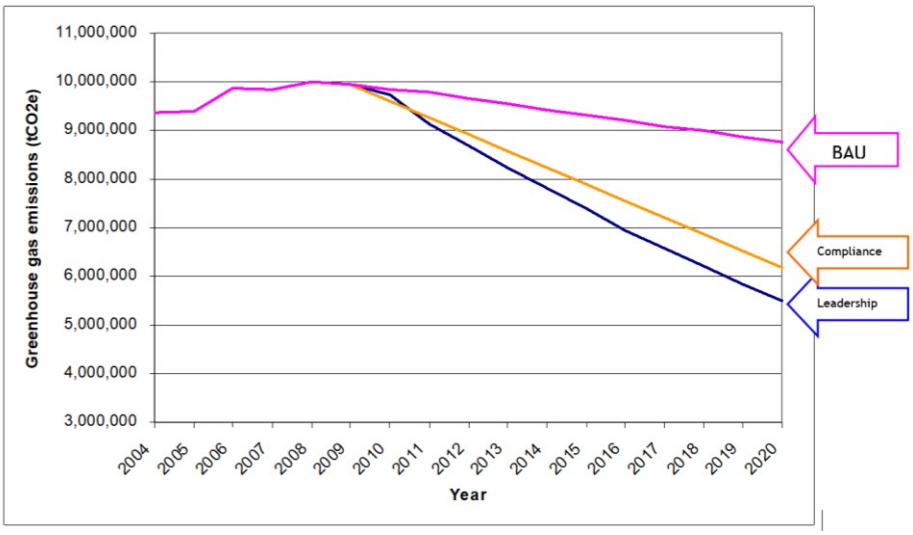


Figure 2: Projected carbon emission trends in English Schools (DCSF, 2009)

Leading up to the year 2020, three possible pathways were recommended for schools, including: Leadership, Compliance or Business-As-Usual (BAU). Using 2004 as the datum or baseline the three pathways differ as follows: the first pathway (Leadership) would lead to a 42% reduction in total carbon emissions by 2020; the second pathway (Compliance) would lead to 34% reduction in carbon emissions; while the last pathway (Business-As-Usual or BAU) will see only a 6% reduction of carbon emissions using 2004 reference levels. The best-case scenario is therefore leadership and the worst-case scenario is to do nothing or continue with BAU (Fig. 3). Obviously merely complying with set guidelines and regulations would lead to significant improvements, but this (34%) reduction is 8% less than the reduction possible by leadership. Nevertheless, the consultation study did not collect or present data about leadership in school's energy and carbon management. Therefore, the thoughts and opinions of school leaders[1] will be critical in the success of a school's carbon management program and this research will exploit the gap by seeking data that could explain the standpoint and readiness of school leaderships.



[1] Leadership of schools here refers to upper management personnel including head teachers, administrators, principals, etc.

Figure 3: Three carbon scenarios for schools in England: Leadership, Compliance or Business-As-Usual (DCSF, 2009)

Interventions for energy efficient school buildings

There are two major intervention programmes that are applicable to schools in England who wish to refurbish their facilities towards improved energy and lower carbon footprints. These programmes are the
Condition Improvement Fund (CIF) and the Salix Energy Efficiency Fund (SEEF). The CIF is a scheme that provides capital funding for academies and sixth form colleges and is sponsored by the Education Funding Agency (EFA). The focus of the funding is to support 'condition projects' i.e. those interventions that will help maintain the eligible schools in a safe, good working or fit-for-purpose state. The issues that would typically be addressed by CIF include: health and safety; energy efficiency; building compliance and poor building condition; continuous heating and water supply as well as weather tight buildings (EFA, 2016). Specifically, the eligible priority work packages that can directly impact energy efficiency include: Block replacement or refurbishment; Boiler and heating systems; Expansion of the gross internal floor area (GIFA); building fabric (weather tightness); mechanical and electrical systems (heating and water supply). The eligibility requirements for CIF restricts it to establishments that are not part of a chain of academy trusts (which have up to 5 academies or a population of pupils exceeding 3000). Schools that are part of an opt-in chain or those that receive 'formulaic funding' are also ineligible to apply for CIF. Projects can be approved under one of three categories as explained below (EFA, 2016): (1) Condition projects: Projects under this CIF category are aimed at improving the general condition of a school building without any expansion to the buildings GIFA; (2) Condition with expansion projects: These projects are also aimed at improving of the general condition of a school building where up to 10% GIFA expansion of the old building is to be done; (3) Expansion projects: Projects funded under this category are aimed at solving overcrowding problems or creating additional places in sixth-form colleges or academies that demonstrate high performance (EFA, 2016). The assessment of all applications made by establishments for CIF financing is based on three main criteria, i.e. Project need (70%); Project planning (15%); and Value for money (15%).

However, some categories of work that are aimed solely at energy efficiency, including lighting, and which do not seek to improve the overall condition of a school are not favoured under the CIF eligibility. Rather, such projects are now supported by an energy efficiency loan scheme through a partnership between EFA and Salix Finance. This scheme known as the Salix Energy Efficiency Fund (SEEF) and provides 100% interest-free loans for Schools to obtain and use for improving the energy performances of their buildings. This funding is available for all schools whether they are traditional academies or large MultiAcademy Trusts (MATs). Therefore, this scheme is more accessible to schools of various kinds and sizes than the CIF scheme. By providing full funding, it is expected that the annual energy savings from such projects will enable them pay back the loans with a period of 8 years. This is an ambitious target that reveals the confidence which the partners (EFA and Salix Finance) have in the cost savings achievable from energy efficiency measures in schools. The experiences of these schools are documented in several case studies, and it would be helpful to appraise these schools based on the core aim

of this research. A case study based archival analysis of selected schools will be carried out as part of the data collection and research process.

The main gaps identified in the review of literature can be summarised as follows. First, the tools used for simulating buildings within BIM processes were not originally designed for BIM, but they are able to integrate with BIM software using geometry-based data exchange formats. This is not an issue for new buildings. However, for the purpose of this research and its objectives which centre on existing buildings, other formats of data required for simulating existing buildings, e.g. data collected from sensors, thermal imagery or data loggers are not directly supported by these BIM software, Second, Energy efficiency in schools is governed by the use of gas and electric equipment as well as the building fabric which governs heat loss/gain. However, the CIF funding which supports the condition improvement of buildings (including fabric or construction work) does not support energy efficient measures like lighting and equipment, which is funded by a different scheme (SEEF). This arguably makes it a challenge for schools because you cannot divorce building fabric from energy consumption by lighting and equipment. Finally, from the three possible pathways for energy and carbon reduction in school's leadership is the most effective, followed by compliance to energy regulations and lastly operating the school under a businessas-usual (BAU) regime. However, there is no evidence or data to suggest that school leadership have been investigated or engaged in order to see if they are providing the kind of leadership that will support energy efficiency measures in their schools either through CIF or SEEF schemes. These gaps will be exploited by collecting primary data in accordance with the logical methodology that is deemed suitable for meeting the objectives of the research.

RESEARCH METHODOLOGY

Research methodology is the strategy that shapes the choice and use of research method or methods (Sobh and Perry, 2006). It entails having a plan of action for a researcher to implement as they carry out their investigation and tends to be influenced by the ontological and epistemological positions held by the researcher (Guba and Lincoln, 1994). In other words, the beliefs or world views held by the researcher will influence their preference for (or perceived suitability of) one method over another. It has been argued that some researchers tend to use the presence or absence of quantification as a basis of establishing the differences between quantitative and qualitative methods as while categorising research methods, but this according to Bryman (2012) is not ideal. Rather, these methods should be viewed on the basis of their epistemological positions, where qualitative method is often aligned with positivism while quantitative methods are associated with interpretivism. When mixed method research (which combined qualitative and quantitative methods) is used, this should be on the basis of taking a pragmatist perspective to finding knowledge (Creswell, 2009; Bryman, 2012).

After careful consideration of the nature and aim of the research, it has been decided that this research will be approached from a pragmatic world view. This position allows the research problem to be in focus always and all the potential methods and techniques that can help address the research objectives/questions should be considered and used as necessary. This

standpoint gives the research greater freedom (Feilzer, 2010; Johnson and Onwuegbuzie, 2004) so that the research (and researcher) is not unnecessarily tied to a particular method as would entail if either positivist and interpretivist worldviews were used. Going forward, therefore, this research has equally considered the validity of qualitative and quantitative methods in addressing the question of whether BIM technology is effective for assessing the energy performance of existing school buildings. The qualitative data can be obtained from interviews while quantitative data can be acquired from archives (documented case studies) of refurbished schools.

RESEARCH METHODS

Given the initial decision to approach the research from a pragmatic worldview and considering the advantages and disadvantages of both quantitative and qualitative research method, it is viewed that mixed method research will be used. Secondary (quantitative) data will be obtained from documented case studies about schools in existence that can shed light about actual energy assessment of such facilities. In addition, the schools that have been involved in energy performance interventions have had various types of measures put in place ranging from space heating to building management systems (BMS) and this will offer a wider perspective on the impact of BIM-based assessments; The case studies are all drawn from the Salix database of schools (https://www.salixfinance.co.uk/loans/SEEF). Primary data from interviews were designed for heads of schools that have benefitted from CIF and SEEF financing. These heads are in leadership position and so the interview can shed light on their level of energy efficiency awareness, as well as their understanding and leadership in the day to day energy performance of their schools.

RESEARCH RESULTS

Case studies of Salix-financed schools

A case study of 10 schools that had benefited from SEEF was carried out. The selected schools (Table 1) were chosen based on four kinds of interventions including: (1) installation of Building management system (Penair School and Scottish Agricultural College); (2) installation of Efficient gas condensing boilers (Whitstone Academy, Harrogate Grammar School, Bedford Hall Methodist School and Meon Junior School); (3) installation of LED lighting systems (St Brides Major Church Primary School and
Foundry Lane Primary School); and finally (4) general lighting upgrades project (Woodridge Primary School and Our Lady and St George's school). From the case study data, it is apparent that the loan value is not a direct indicator (or directly proportional) to the annual or lifetime savings. For instance, the loans taken by Foundary Lane primary school (£27,019) and Meon Junior school (£18,000) are significantly different. However, the lower amount spent by Meon Junior school led to 211% lifetime savings because it was spent on gas boiler refurbishment whereas the higher loan taken by Foundary Lane primary school that was spent on LED lighting delivered a 182% lifetime saving. Nevertheless, even though the annual savings of CO_2 from

the costlier loan (15 tonnes) was only slightly more than the annual savings of the cheaper loan (12 tonnes), the lifetime savings of CO_2 is more favourable to the costlier LED lighting project.

Table 1: The case study data for 10 schools which took Salix-finance loans[1]

Case ID	Project	Description	Documented year	Loan value	Annual Savings	Lifetime savings	Lifetime savings as % of loan	Annual savings of CO2	Lifetime savings of CO2	Calculated years of CO2 savings	Project payback
1	St Brides Major Church Primary School	LED lighting project.	Dec-13	10,125	2,218	28,840	**285%**	11	150	**13.6**	4.5
2	Foundry Lane Primary School	LED lighting project.	Dec-13	27,019	3,784	49,191	**182%**	15	196	**13.1**	7.1
3	Scottish Agricultural College	Building management system.	Nov-12	120,341	49,229	172,301	**143%**	322	1126	**3.5**	2.4
4	Penair School	Building management system.	Nov-12	5,358	2,524	21,256	**397%**	12	98	**8.2**	2.1
5	Whitstone Academy	Efficient gas condensing boilers.	Sep-16	220,000	27,500	275,000	**125%**	NA	NA	**NA**	7
6	Harrogate Grammar School	Efficient boilers and new zone controls.	Oct-16	223,323	34,343	343,430	**154%**	NA	NA	**NA**	6.5
7	Bedford Hall Methodist School	Efficient boilers and heating system.	Nov-16	49,278	11,266	124,280	**252%**	NA	NA	**NA**	4.4
8	Meon Junior School	Oil to Gas boiler fuel switching project.	Dec-13	18,000	4,802	38,032	**211%**	12	92	**7.7**	3.8
9	Woodridge Primary School	Lighting upgrades project.	Dec-13	4,438	1,379	13,790	**311%**	5	5.8	**1.2**	3.2
10	Our Lady and St George's	Lighting upgrade and installation of PIR controls	Nov-16	47,401	6,304	152,497	**322%**	NA	NA	**NA**	8

Similarly, it could be deduced that whereas Penair School took a loan of £5,358 to spend on Building
Management System, leading to lifetime savings of £21,256 and lifetime CO_2 savings of 98 tonnes, the £4,438 loaned to Woodbridge primary school that was spent on lighting upgrades produced a lifetime saving of £13,790 and lifetime CO_2 savings of just 5.8 tonnes.

In summary, the case study data suggests that schools have probably not been strategic in the amount they take as loan or in the types of projects they spent it on (for instance, spending similar amounts of money on lighting upgrades rather than on BMS which would save more carbon). Although it is expected that a school embarking on a costlier type of refurbishment is responding to a need, it is pertinent for the school administrators and designers to study the long-term impacts and make informed decisions accordingly. This is clear from the Penair vs. Woodbridge school projects where the loan amounts are not too dissimilar (£5,358 and £4,438 respectively), but the lifetime savings are drastically different (£21,256 and £13,790 respectively) or 98 tonnes of CO_2 against a meagre 5.8 tonnes of CO_2 respectively.

4.2 Interviews of heads of schools

Interviews were required to engage with several heads of schools across the UK to collect qualitative data about their experiences with SEEF projects implemented in their facilities. A total of seven interviews were carried out from the 13 respondents who indicated interest in participating (Table 2).

[1] In this case study table, the data found in Column 8 (Lifetime savings as % of loan) and Column 11 (Calculated years of CO2 savings) were computed and not part of original data.

Table 2: Summary of interviewees

Interviewee ID	Location in UK	Official Title	Years in role	Type of SEEF project	Age of building
Interviewee 1	East Midlands	Head teacher	4 years	New Boilers	Victorian
Interviewee 2	East Midlands	Head of School	5 years	BMS and sensors	2000s
Interviewee 3	London	School Administrator	3 years	Lighting upgrades	Late 1940s
Interviewee 4	West Midlands	Head Tutor	2 years	LED Lighting	Unknown
Interviewee 5	London	Head Teacher	3 years	New BMS	1990s
Interviewee 6	East of England	School Director	5 years	LED Lighting	Unknown
Interviewee 7	West Midlands	Head of School	3 years	Efficient Boilers	Victorian

From the transcribed interview data, five themes and eleven sub-themes emerged (Table 3) and the relevant verbatim comments extracted from the transcribed data is presented in Appendix 1. The major themes that emerged have been classified as follows: Handing over of buildings; Capability to manage modern energy systems; Integration with existing systems; Support for Measuring and monitoring CO2 savings; as well as the CIF and SEEF funding process. The themes categorised above (Table 3) were generated from the verbatim transcription of qualitative data collected from seven interviewees as summarised in Appendix 1. The transcription of the interview data and generating the themes that emerged, has provided some interesting insights about the processes used in procurement of energy efficient systems. In all cases, the respondents were either heads of school, head teachers or some form of top ranking school administrator whose approval, input and authority must have mattered (in addition to elected boards of governors) towards the decision to apply for SEEF funding and the eventual expenditure. Therefore, these respondents and the data they generated must be regarded as a valid representation of the views of leadership of schools, i.e. the individuals whose guidance is thought (in literature) to be essential for meeting the 2050 carbon reduction targets. In some cases, the leaders have been proactive in adhering to the advice/guidance of the Carbon Trust but in many cases, they are not enlightened enough about BIM, GSL and post-occupancy management issues that determine the effectiveness of energy efficient measures.

Table 3: Interview data summarised into 5 themes and 11 sub-themes

Major themes	Sub themes	Interviewee 1	Interviewee 2	Interviewee 3	Interviewee 4	Interviewee 5	Interviewee 6	Interviewee 7
Handing over of buildings	***Type and location of maintenance information***	Not sure	We have hard copy O&E manuals	This is available in PDF	No response	Kept by maintenance contract firm	Hard copy kept in mechanical room	We have soft copies and hard copes
	Technical language of manuals	Somebody else reads manuals	Too complex to understand BMS manuals	Have not read it so do not know how easy	System came with printed manuals, easy to read	Operating manuals are not easy to understand	No response	Relying on external company for major issues
Capability to manage modern energy systems	***Availability of expertise in schools***	Not an issue, we have expert	We manage systems ourselves easily	Easy to understand and manage sensors and lighting controls	Form tutors in charge of LED control systems	Too complex for staff to learn/use	Automated lighting is sometimes faulty	Janitor is trained by school to manage system

	Sophisticated controls and user-friendliness	Boilers have simple control systems	BMS controls not easy to understand	Lighting controls are use friendly	Not sure	BMS managed and by external staff	Easy to use lighting controls	Boiler controls are very complicated
	Use of external companies	Not responding on time to requests in winter	No comments	Cost implications	Do not need outside help to manage	Additional cost of paying for expertise	Not sure	Running cost not easy to cover in budget
Integration with existing systems	***User control of new vs. old systems***	No comment	Motion sensors are helping to save energy	Infra-red sensors are helpful	Quality of lighting varies across facility	Issues with old controls and new BMS systems	Sometimes difficult to fix LED bulbs	Control systems are easier (touch screen)
	Analogue vs. Digital systems	Not sure	Operating digital and analogue systems concurrently is challenging	No response	Control systems do not work with non-LED lights	Not every part of facility uses BMS, some are old systems	LED lit rooms are preferred to rooms with older systems	New boilers are less noisy
Support for Measuring and monitoring CO_2 savings	***Know-how for carbon monitoring***	Do not know how CO2 is measured or monitored	Need training on carbon and energy efficiency	No response	No response	Not sure who might know this	Lack of expertise in carbon monitoring	Do not know how carbon is monitored of measured
	Real-time smart meters	Need smart CO_2 meters	Smart meters don't measure carbon, only energy used	No response	Smart meters were not installed	Do not think carbon is measured in our smart meters	Smart meters are helpful but not installed in every building	No response
CIF and SEEF funding	***Obtaining funding and payback period***	We had to submit application twice due to complex process	We wanted both CIF and SEED funding but had to settle for SEEF	Did not get enough money to cover entire school	Payback period is too short	Funding not enough to solve condensation problems	Process seemed too tedious for a lighting project	Not sure we will meet the payback period
	Financial vs. Technical advice	Boilers more expensive than budgeted	Needed more advice about the payback period	No response	No response	BMS saving money through automation	No response	Decision to invest needed maintenance team's input

DISCUSSION

The data collected from case studies suggests that there are a few instances were value for money was not realised or maximised. Some schools do not seem to be making informed and strategic decisions on the loan amount and what they spend it on for refurbishment. Interviewee 2 and 5 for example, stated that they needed help in making such investment decisions and the case study data suggests that although a school embarking on a costlier type of refurbishment may be responding to a need, yet where the loan amounts are similar (£5,358 and £4,438 taken as loan by Penair and Woodbridge schools respectively), the lifetime savings can be considerably different (with savings £21,256 and £13,790 respectively for these schools). There was also a significant carbon saving difference between them, i.e. 98 tonnes of CO_2 (Penair) against the relatively smaller 5.8 tonnes of CO_2 saved by Woodbridge. The significance of these results is that Penair spent their £5,358 on building management systems, while Woodbridge school spent their £4,438 on lighting upgrades. The difference that the additional £920 has made to the lifetime savings and carbon emissions savings makes it a

better investment and value for money. Although, the uncertainty here is that Woodbridge may already have a BMS in place, this is unlikely since many BMS systems are typically linked with sensor based lighting systems. Therefore, their decision to invest in lighting upgrades as opposed to BMS could have been better informed. The case of Penair vs. Woodbridge school is an example of where professionals can provide guidance because although it is the administrators who apply for loans, the professionals who ought to be aware of energy assessment software and energy assessment standards were probably not involved in the application process. Or perhaps they were involved but did not give the schools the best possible guidance they need to make such investments, but this could be due to the limited expertise of the professionals.

The energy efficiency and carbon reduction decisions taken by school heads are important to the process. This point is buttressed by literature where it was reported that leading up to 2050, leadership was central to meeting low carbon targets, as opposed to mere compliance or carrying on with business-as-usual (DCSF, 2009). It was nevertheless found that some interview respondents [Interviewee 1, 6 and 7] were using the Carbon Trust's guidance on energy efficiency in schools. These respondents were referring to the "Good Practice Guide - 343 (GPG343), Saving Energy – A whole school approach" (Carbon Trust, 2003). It was a welcome development that they would implement guidance if it was provided to them. However further carbon education might be required because some respondents stated that: they "*Need smart CO_2 meters*" [Interviewee 1]; and their "*Smart meters don't measure carbon, only the energy used*" [Interviewee 2] or that "*we do not think carbon is measured in our smart meters*" [Interviewee 5]. These statements demonstrate the naivety among school heads who do not realise that carbon is not measured / metered as easily as electricity or gas. Such naivety may also be prevalent in other facets of the AEC industry.

Nevertheless, whereas Interviewee 1 thought "*We lack technical know-how to advise colleagues and students about boilers and energy efficient practices, but we have Carbon Trust guidelines*", Interviewee 5 argued that "We depend on automation of systems to help us manage the use of buildings. This seems better than depending on people". This point resonates with the findings of Palmer and Cooper (2012) who found that using sensors to reveal actual human behaviour would provide more accurate energy utilisation information than using simulations. However, this should not detract from the usefulness of simulations in predicting the patterns of energy usage. As argued by Shorrock, et al. (2005) most refurbishment work tends to be on envelope and insulation, yet the automation of lighting controls using infra-red or motion sensors [Interviewee 2 and 3] and the use of BMS demonstrates the paradox of funding available to schools, i.e. they either apply for CIF to fund the envelope or apply for SEEF to fund the energy systems, whose efficiency depends on heat loss/gain across envelopes. Perhaps these schools could apply for both funding schemes (obviously at different times) but the fact that the schools investigated in this study (SEEF beneficiaries) were constrained from partaking in CIF applications is a major constraint given the scope and focus of this research.

Interviewers 2 and 5 respectively said "*We had to rely on expert advice about our capability of meeting payback period*", "*Our school is rather old, so I am not sure we got the correct advice about payback period. The BMS helps to cut our bills*". Interviewer 1 said "*we needed some*

advice during the application process", but in one instance [Interviewee 6] the investment decision was deferred to the maintenance team. Interviewer 5 said "*We work with a tight budget and we had to outsource our maintenance needs on contract basis*". The heads of schools (and perhaps board of governors) who are in a best position to provide leadership in carbon and energy reduction targets seem to be not properly educated about important strategies like government soft landings, as suggested by interview data. The school heads interviewed were generally not aware of any post-occupancy or lifecycle use of BIM to manage their facilities although a few [Interviewees 1, 2, 3, 5 & 6] seemed to be vaguely familiar with 3D BIM (Table 4).

Overall, there was a consensus among the interviewees that the energy efficiency of their schools improved after SEEF intervention projects (Table 4) the data points to the inherent link between energy systems and building fabric; e.g. "*We do have condensation problems, but our heating bills have gone down*" [Interviewee 5] and "*we are benefiting from the new energy efficient boilers, but the fabric of the building is quite old*" [Interviewee 7, whose building was of Victorian age]. There are established methods of building pathology which could have helped designers with insights into the age environmental conditions (Golparvar-Fard and Ham 2014) e.g. the use of thermal imaging integrated into gbXML models that are compatible with BIM (Ham and Golparvar-Fard, 2015). Although the data from this study suggests thermography is not used during SEEF refurbishment, it is possible (but doubtful) that it is used even in CIF refurbishment of the physical envelope of schools. This again points to the problematic separation of funding purposes in SEEF and CIF projects. The insights from interview data and established literature raise questions about the wisdom of the policy that constraints schools to applying for either CIF or SEEF but not both, since building age influences heat transfer across building fabric regardless of how modern or efficient the lighting or energy systems might be.

Integrating real-time data collected by energy management systems with as-built 3D BIM models has been shown to be helpful for diagnostics and fault-detection in existing building (Dong, et al., 2014). However, without using such modern building pathology techniques (including energy simulation and thermography), the process of refurbishment may lack the accuracy required, even if when energy-saving systems like BMS are installed, as evident with Interviewee 5 who highlighted the condensation problems that remained after refurbishment. Arguably, the separation of SEEF from CIF funding is not helping. For example, a school wanted both SEEF and CIF funding but had to settle for only SEEF [Interviewee 2]. Such separation means schools are setting for less than optimal ways of reducing their energy and carbon consumptions as further discussed in the next section.

CONCLUSIONS

The funding model for refurbishment of state schools is primarily based on Condition Improvement Funding (CIF) loans or Salix-financed SEEF loans. At the point of application, these funding routes are mutually exclusive whereas from the technical and engineering perspective, the envelope and general condition of a school building (with or without expansion to the GIFA) covered by CIF influences the energy effectiveness of lighting and equipment covered by SEEF.

Therefore, the financial model needs to be revisited from a holistic and engineering point of view. Without active intervention to mitigate the carbon footprints from such schools, the carbon emitted from such schools will remain at their levels up to the year 2050. Therefore, leadership and initiative is thought to be a key determinant for meeting carbon reduction targets but the apparent lack of exposure to BIM concepts like GSL and COBie by heads of schools is problematic. Although some of these leaders are exposed to best practices published by Carbon Trust UK, these practices (Good Practice Guide 343 (or GPG343)) are essentially recommended benchmarks basic operational issues and everyday practices that school residents could adopt to save energy. The use of the stated toolsets for facility management is crucial to achieving the objectives of GSL. The schools that have benefitted from SEEF initiatives have largely benefitted from systems that enable them measure and control direct energy. For instance, the use of sensors for motion detection during lighting upgrades and smart meters that work with BMS has been widespread. These are not necessarily useful for monitoring carbon emissions and other forms of energy performance indicators or metrics like CO_2 monitors which are helpful for indoor air quality as well as airflow and water pressure and consumption monitors (helpful for sustainable use of buildings) do not appear to be used in schools. Given the three carbon reduction scenarios established in literature, i.e. Leadership, Compliance or Business-As-Usual, schools are not showing 'leadership' in reducing carbon. The steps they are taking to refurbish their facilities, is analogous to 'compliance' at best since they are and in many respects following the processes required to get energy efficient systems. However, in many respects, it could be said that they are carrying on with BAU since for example they are not able to receive CIF funding necessary to upgrade the fabric of buildings. Other important aspects of diagnostics and faultdetecting in existing building rely on integrating real-time data collected by energy management systems with as-built 3D BIM models; and the age and environmental conditions of buildings is critical for successful modelling and simulation. However, case study and primary data collected and analysed through interviews suggest that these modern techniques of diagnosis and building pathology are not used in the refurbishment of school buildings.

The recommendations that can be made from the findings of this study include: (i) heads of schools should be given intensive training on how the GSL is integral to the energy efficient and sustainable operation of their facilities; (ii) since the use of BIM has mandatory since April 2016 on all government funded projects, and the loans given via CIF and SEEF are underwritten by government, it should be made clear to professionals that school refurbishment projects should not be an exception, especially since no financial limit (or threshold) has been placed on projects for using BIM; (iii) training would be required for professionals and their organisation who do refurbishment so that they adopt modern processes (e.g. using NBS BIM Toolkit) or technologies (e.g. thermal imaging for fault diagnostics). This is because refurbishment of schools is likely to be done by SMEs who are known to be financially and technically challenged in adopting BIM, and as such, incentives and technical support should be given to them to bring them up to speed with modern developments; (iv) government agencies in charge of approving loans to schools should revisit the policy of granting only one kind of financial instrument (i.e. CIF or SEEF) and make it possible for schools to receive support for improving both the physical condition (CIF) and energy efficiency equipment and systems (SEEF).

Limitations of study and suggestions for future work:

This research is not without limitations. This paper has focused on SEEF funded schools with metrics that only cover cost, energy and carbon emissions. Therefore, schools that have opted for CIF and other education-related matters have already been excluded from the data collection and analysis. Given the scope of subject matter (e.g. refurbishment of SEEF funded schools), interview questions were focused on energy and cost issues. Interview questions could have included other metrics such as "the quality of life of building uses" and "the rate between graduated pupils number and carbon emission emitted by the building". This would have provided a richer set of data for comparative assessment and analysis. These limitations were imposed by time and accessibility constraints but can be addressed in future work through careful design of data collecting instruments and, of course, cooperation of heads of schools.

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DESIGN PATTERNS AS A COLLABORATIVE ENTITY WITHIN THE SMART ENVIRONMENT

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Keywords: Design patterns, Smart Environments, Collaboration, Processes.

Abstract

Modern technology is increasingly being employed to create a "smart" living experience. These "smart" technology entities are producing copious of amounts data, which in turn rely on increased storage, distribution and computation needs to manage the data. Depending on the scenario, the diversity of piecemeal solutions almost mirrors the numbers of problems posed. Some successful solutions touted as being "smart" for example: save energy, or to support in assisted living, have been created, but the true underlying pattern of interactivity has not been identified. In the field of computing, patterns can provide a general, reusable solution to commonly repeatable occurring problems within a given context through software design. Similarly, can a technology-independent design pattern format and an open software framework be developed to capture, share and redeploy existing successful and reusable strategies for commonly encountered smart environment use cases in areas such as assistive technology, energy management and environmental monitoring? The underpinning notion of this paper is to introduce "how, where and why" a rule set based in "design pattern" format could contribute to describe a general "understanding" of given cases in the smart environment domain, as well as allow different processes to collaborate with each other. At this point, our project performs a preliminary research on how different communities use popular logic encoding paradigms to essentially represent the same idea; a set of conditional statements. With a view to determining a framework that could be used to define the interconnection among each process. This paper extends previous research by exploring different uses of patterns in the domain of software architecture and design. Ultimately, our study aims to link the principle of "rule of thumb" to the concept of design patterns, by making this accessible enough to allow successful "smart space" solutions to be shared widely between outstanding solution providers.

INTRODUCTION

A pattern is a regular and comprehensible "form" or sequence discernible in the way in which something happens, is prepared or is completed and contributes to guide or solve common reusable design issues (The free dictionary, 2017). However, patterns are not solely a human invention, patterns occur naturally in various contexts, such as, nature, art and architecture, computer science, process optimisation and so on, allowing humans to mathematically model/generalise processes. Patterns can also be used to gauge the past, present, and future: archaeologists use the layers of earth to date their findings. Many

others have been able to translate them into maths, geometric shapes and building equations, which are used by computers to simulate a wide range of biological processes (Wikipedia, 2018). In software design, patterns can provide a general, reusable solution to a commonly occurring problem within given context parameters. The *term design patterns* relates to the way in which a recurring design issue is identified, labelled, and coded in order to provide a general solution (Wikipedia, 2018).

This paper attempts to describe a preliminary design-pattern approach for smart processes.

LITERATURE REVIEW

Design patterns emerged in different problem domains, and have being widely applied to a multitude of design techniques. However, computer design has become a major torchbearer for pattern research. In 1977, Christopher Alexander introduced the concept of a pattern language, composed out of 253 of these elements (Alexander, C.,1977). Alexander's work provides, not only to professionals but also to non-technical people, a tool with which to improve a town or neighbourhood, design a house or work with others to design different spaces. Pattern based design employs a catalogue of notions to be considered without needing to resort to mathematical or algebraic expression to describe the patterns, or their application. Nonetheless, his work has had a considerable impact on computer engineering. In this field, Alexander's contributions are applied to Object Oriented Programming. These theoretical structures enable the linking together of objects in programs in a co-operative and sequential way. The significance of this approach has motivated the appearance of conferences such as Pattern Languages of Programs (PLoP) (Conference on Pattern Languages of Programs, 2018).

At the time that patterns were being developed in computer science, a shift occurred in the field of human-computer interaction (HCI) research, from focusing on how people interacted with programs towards a communications oriented approach. This happened mainly because of the growth of the Internet and the web. As a result, the number of research fields grew under the umbrella of HCI (Dearden, A., 2006). By 2005, the research focused on collaboration, connection and communication (Lazar, J., 2010). This coincided with the period in which the Internet of Things concept emerged. The reason for this shift in emphasis, was the opportunity that Internet gave to technologists for communicating wirelessly. It made it possible to digitise data transfer by transitioning from analogue to digital formats. The next phase was digitalization, which focuses on business rules and systems that synthesize and manipulate digitised information. An example of this is the intelligence behind the ever changing and adapting Google search engine. It involves far more than simply accessing digitised data.

Based on the two terms mentioned above, *design patterns* and *HCI*, researchers have focused their efforts towards new approaches to improve the experience of the users within *smart spaces* (Vega-barbas, M., Pau, I., Augusto, J., 2017). In the same way, different studies have tried to define a mathematical model to describe context within smart spaces (Yang S., Kabir, M., Hoque, M., 2016).

The concept of *context* is needed when we discuss and evaluate meaning. Somewhat ironically, this term has often been used in different senses. In the field of logic, the philosopher C. S. Peirce introduced for the first time a representation of context as a

formal object. From 1980, three main theories highlighted this concept of context: Kamp´s discourse representation theory; Barwise and Perry´s situation semantics; and Sowa´s conceptual graphs (Sowa, John F., 1995). In essence, popular identification techniques and frameworks to efficiently capture and manage context are funnelled into discipline specific solutions. In the Artificial Intelligence literature, there is no single authoritative definition of the concept of context in the form of a universally accepted identification or framework, however, it is widely employed in different approaches. The difficulty is when two or more systems (or approaches) need to interact to provide a more comprehensive solution.

METHODOLOGY

This first phase of our work involved an initial investigation of popular diagram based pattern formats used by a variety of expert communities. The objective was to uncover commonality of identification and structure and possible links to algebra hidden within diagrams. Table 1 shows the layout used to describe the different logical elements.

Category	Symbol	Description
Name	Image	• Year created. • Attributes. • Purpose. • Intended use.

Table 1, Logic description properties.

This analysis is motivated by the necessity to identify common structures used in different fields, by different communities, applying and using different design-methods, symbols and descriptions to build logical sequences. All of them based on the same fundamental principle.

These diagram nomenclatures represent broadly the same idea, which is, the development of a common framework which could unify and simplify the use of different instructions under the same umbrella of a pattern format. By doing so, we aim to set the basis for a collaborative pattern-based model which will enable cooperation between different processes within the smart-living domain.

In addition, our search has led to an analysis of different processes aiming to identify the main elements of a generalised pattern. A whole process, overall, can be decomposed into smaller parts, in the same way that an image is made up of pixels. Each of these parts carries its own portion of meaning. The combination of these parts, among other things, add meaning, and context to the process. Context, in our approach, means we can consider collected data as information that can be reused and applied in different solutions. In Table 2 we list the different sub-elements, in which we have split each process.

Process Name
Triggering Events *(Conditions that must be met at the beginning of the process)*
Terminating Events (These are the conditions that must be met at the end of the process)

Inputs (The resources needed to execute the process)
Outputs (The items created as a result of the process)
Sequence (These describes the steps in the process along with the actors responsible for executing each step)
Conditions
Metrics (Attribute) (What aspects of the process are measured)
Sample Images

Table 2, Decomposition of a process.

Each of these elements describe an essential and individual part of the overall process. Each individual piece can have its own meaning, but as a collaborative whole, they produce a process, with contextualised meanings. Interaction between different elements is a critical aspect to capture.

This paper will present a preliminary approach in which the concept of design patterns can be applied to identify patterns within the daily routine of a stakeholder within the smart living experience. This concept is described as follows, by common iconography.

Patterns within activities

As mentioned above, our research is focused on smart environments. Here, a great variety of scenarios such us a home, a hospital or an art gallery may be contemplated. Furthermore, in each environment, every user interacts with it in a particular and unique way. Figure 1 highlights three different user routines within three different smart environment.

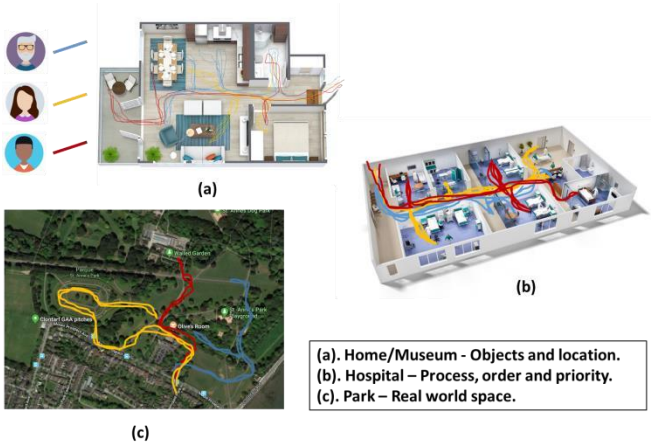


Figure 1. (a) Smart home routine. (b) Smart Hospital routine. (c) Real world routine.

In Figure 1-(a), which may correspond to a home or museum, we can find Objects, and Localisation. These general design elements can be used for example, to build a system to guide a user through an art gallery. While in Figure 1-(b), at a Hospital scenario, Objects may have different priorities within the whole process followed by the user, in which case a defined sequence must be followed in a particular order. Other case, Figure 1-(c), of interaction within the environment is the real world scenario, for instance a park, where

each person may interact in a different way, following personalised routines and preferences.

Each of the paths drawn can be described as a process or sequence of transitions between different nodes or states. Each of these nodes may represent a position, which can be defined by its localisation, context, or metadata. Furthermore, each node can refers either to a zone Figure 2-(a) or an activity Figure 2-(b).

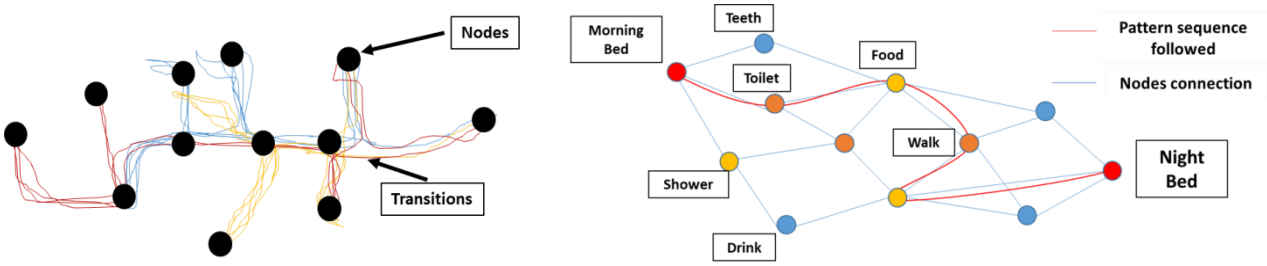


Figure 2. (a) Nodes as positions. (b) Nodes as activities.

On the other hand, the transitions or connections among these nodes or states illustrate the order or priority of events along the processes in which the different activities are carried out. These shapes described how people interact in different ways with their environment, allowing to define a *pattern routine* of each user within smart environments.

Reshaping different Smart Objects into a pattern-format

Figure 3-(a) symbolises nodes or states from different smart environments. Then, there is a need to develop a common structure which shapes nodes from different processes or scenarios. At this stage, an analysis of design-pattern techniques aims to identify and perform the most accurate pattern-form, which will enable the re-building of data into a common format.

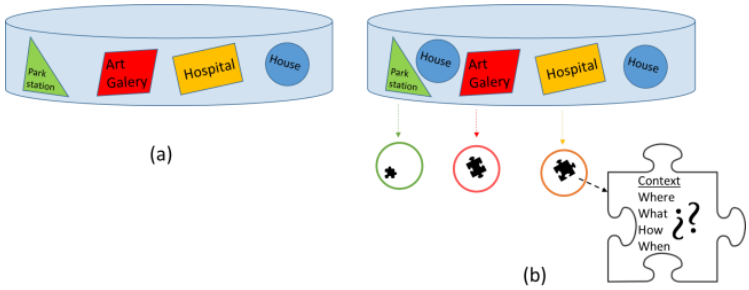


Figure 3. (a) Nodes from different processes and scenarios. (b) Nodes structured into a pattern based format.

A study published by Alexander proposed a game card structure for this purpose (Kumo Brian, 2018). In line with Alexander's proposal, nodes from different scenarios and processes will be stored and re-structured into a uniform format, as shown in Figure 2-(b).

This pattern-based model aims to act as an enabler for the main purpose of the tool as a whole, which is for collaboration among discrete smart solutions.

Describing understanding within processes

As a model that attempts to provide new generic solutions from the activities carried out in different scenarios of the smart environment domain, understanding the possible connections between nodes, and so capturing context becomes a requirement.

Following the discussion of some of the problems relating to context from section 2, our study performs a theoretical investigation of the properties shared by natural languages. This analysis is intended to reveal the underpinning principles behind the natural languages to provide understanding that can be applied in our approach to capturing a notion of context in logic processes. A programing or artificial language is defined as a formal language that specifies a set of instructions that can be used to produce different outputs. Furthermore, a natural language cannot be easily understood and interpreted by computers. In order to achieve this we need to be very specific about giving commands or asking for information. Therefore, can a set of rules be described to capture context within processes?

Hence, our approach studies the rules that apply to natural languages, and provides a preliminary graphic which seeks to gather the elements required to build sentences that are meaningful in the sense of computability. Our aim is to describe the basis for capturing context within patterns. The nodes described and shaped into pattern-based structures needs to be analysed in order to provide a notion of context. This is needed because users will interact differently with the environment depending on their needs. For example, guiding to a user through an art gallery will vary the transition from one state to another in case it is required to move from one floor to another of the building and the user moves in wheelchair, thereby avoiding stairs or obstacles. Therefore, from a collaborative perspective, context enables different nodes to interconnect. In Figure 4, context is represented as a black puzzle piece within each block. Besides this, Figure 4 is intended to symbolise the concept of collaboration between different solutions gathered within smart spaces.

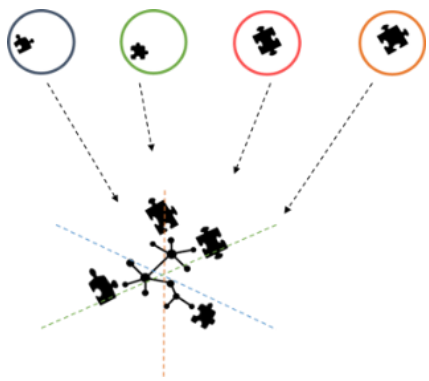


Figure 4. Context within pattern structures.

The study of languages is often segregated into syntactic, semantic and pragmatic components (Sowa, John F., 1995). Similar patterns of division are employed in other disciplines. For example, in computer science an ‘if’ or ‘while’ loop has a common syntax

structure, semantic elements to describe the condition which applies to that loop and finally the pragmatic elements relating to the real-world effect of what the 'if' or 'while' loop is supposed to achieve. By illustrating the three components as separate axes in Figure 5 we begin to uncouple the components so they can be closely examined.

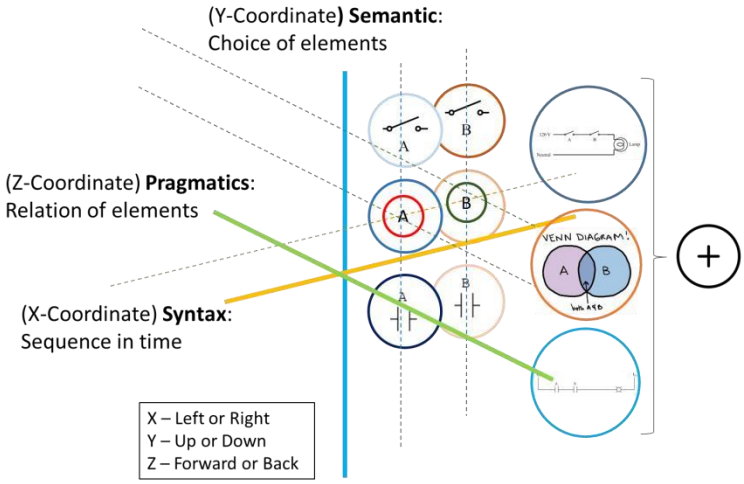


Figure 5. The rules of languages used to describe processes.

The syntax refers to the sequence in time in which the event occurs. Also, it represents the form of a valid structure. Though, it does not provide any information about the meaning of the sentence, program or results. The syntax of a process is represented by the natural sequence of steps.

The semantic or choice of elements, handles the meaning given to a combination of symbols. Yet, this first piece of information is not enough for a full understanding of why or what is described in the process. It is represented on the vertical axis because each block, which may be a physical entity, a mathematical construction, or some other expression in a natural or artificial language, can be associated with different meanings, altering the whole understanding of the linguistic sentence or process.

From a linguistic view, it can be sub-divided into 3 categories or levels namely Sentence, Phrase and Word Level.

Therefore, by following this division, the nodes can be categorised into different levels depending on their meaning.

Finally, the pragmatic will be drawn onto the Z-coordinate providing the purpose. The meaning in context of every process. Referring to how the user interacts with the piece of environment described within each node, and to the relation of elements and sequence of extra-linguistic information. Helping to understand how context aids the transmission of meaning in utterances.

However, these elements do not exist independently and can only be understood in terms of their interrelationships.

RESULTS

In order to analyse the different community nomenclatures, Table 3 provides an idea of different popular nomenclatures for representing patterns that is an extract of previous work by the authors (Arribas A., McGrory J., Berry D., 2017). In this case the pattern is a simple conditional statement.

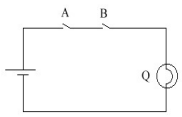
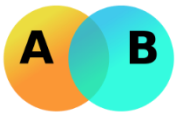
Category	Symbol	Description
Circuit/Wiring diagram		**Year created:** 1820´s (Circuit diagrams, 2018) **Attributes:** It combines addresses and datatype/value components. **Purpose:** illustrates actual wiring of the circuit. The logic is implicit to the user knowing the devices and the physical flow of electricity. Suitable for physical layouts and implementations for non-technical persons. **Intended use:** to guide workers who may be unskilled on the desired layout and placement of wires and devices.
Venn diagram		**Year created:** 1880 (Ruskey F.,Weston M., 2005) **Attributes:** Combines addresses and datatype/value components. **Purpose:** Technical or non-technical. **Intended use:** Graphical representation for non-technical persons and uses the pattern matching and grouping ability of humans.

Table 3, AND logic used in different communities.

All of the diagram nomenclatures, in Table 3, represent broadly the same idea, which is, the development of a pattern-based model which could unify and simplify the usage of different instructions under the same structure.

CONCLUSION

This paper has highlighted the phrase “design pattern” is an inclusive term referring to a repeating arrangement of an entity or combination of entities, such as, shape, influence, impression, form, function, fit, model, fashion, etc. For example, if we take a simple arithmetic expression, where operation such as ‘+’ is performed, Figure 5, we can state ‘4+3’, ‘A+B’, ‘X AND Y’, but we can also express ‘+’ graphically as shown in Table 3. The AND operation is, therefore, in essence, a “design pattern” where, each of these expressions achieve the same goal.

However, what brands these AND expressions as ‘different’, ‘not compatible with each other’ and ‘not cross compatible’ is not the concept or notion of a repeating arrangement, but more specifically the incompatibility of the entity types (through lack of context).

Our work hints at an a technique, where if we can identify, record, describe and structure elements contained in the smart environment, we begin to open the door to crosscompatibility and then to collaboration. Areas such as assistive technology, energy management and environmental monitoring each use these design patterns extensively, but an obstacle issue is cross-compatibility and lack of context and situation awareness.

Future work, will test the designed pattern framework system and to show how the resulting patterns can be transferred to a “living laboratory‟ smart environment test bed being developed at the Greenway Hub / ESHI Building at DIT Grangegorman.

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THERMOCHEMICAL HEATING/COOLING STORAGE MATERIALS IN ENERGY SYSTEM FOR BUILT ENVIRONMENT

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Keywords: Thermochemical energy storage (TES); energy storage materials; energy storage system; open energy storage system.

Abstract

More than 40% of energy consumption occurred in building system with 36% of greenhouse gas emissions. In the UK, a major of 63% energy end-use for space heating/cooling for a comfort building condition. Thermochemical energy storage can be a promising advanced technology in addressing massive energy use for heating and cooling in building application. The system can be an alternative to the conventional energy system because of the lower heat loss, higher energy density of the materials, more efficient and environmentally friendly. In this paper, we used different high energy density storage salts (e.g. $CaCl_2$, $MgSO_4$, LiCl, $MgCl_2$) with host matrix such as vermiculite and advanced carbon. The aim of this paper is characterize different composite to find better performing materials with higher energy density, lower heat loss, lower regeneration temperature, higher temperature lift in reaction process and higher system efficient. The pore size of each material was identified by using Mercury Intrusion Porosimetry (MIP), and the energy density of each material was tested using SDT-Q600, the SEM images showed the nano-size detail of composite materials.

INTRODUCTION

The increasing pollution and energy bills lead to a growing interest in clean energy to reduce greenhouse gas (GHG) emissions and save energy consumption. Energy system covers a broad range of activities including renewable energy generation, schemes to help domestic and commercial consumers to reduce energy. It should be a key part of any local authority's strategy to drive down the carbon footprint and energy costs. Conventional technologies use some refrigerants with high ozone depletion potential that harmful for global environment and lead to global warming. The new thinking on renewable energy development will be a solution to meet environmentally friendly and human needs.

Thermochemical energy storage (TES) have been researched to face the issue of GHG emissions and large energy consumption in the built environment (Yanan Zhang, 2017). Compared with sensible heat storage system and latent heat storage system, TES system has significant advantages, such as it has 6-10 times higher storage density than sensible heat storage and double the storage volume basis of latent heat storage, and also, TES materials have relative low regeneration temperature and provide seasonal storage (Casey S, 2015). TES system is an innovative, promising alternative way to reduce high energy consumption and GHG emissions.

The idea of thermochemical energy storage system is to storage heat and cool in thermochemical materials as 'thermal battery' for later use, such as PCM and exothermic/endothermic materials (Casey, Aydin, Elvins, & Riffat, 2017). A novel open thermochemical energy storage systems will be given in this paper. 'Open' means the whole system is connected with the surrounding environment. The principle of the open cycle TES system is shown in **Figure *1***. In the reaction process, water vapor adsorbed on desiccant to release (for heating process) or absorb (for cooling process) heat when moisture air goes through the adsorbent materials (exothermic materials for thermochemical heating and endothermic materials for thermochemical cooling process). In the regeneration (charging) process, warm and dry air passes through the wet desiccant and take away moisture to dry the TES materials and store energy inside the TES materials.

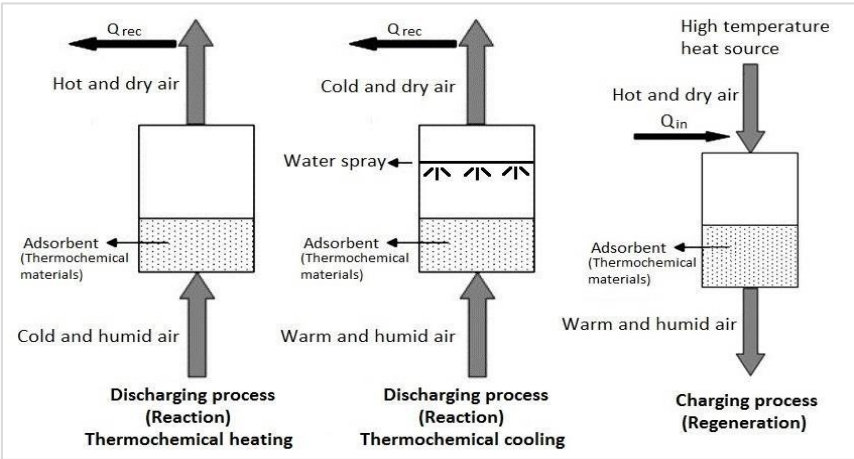

Figure 1. Charging and discharging process in open thermochemical energy storage system.

SIMULATION

Initial simulation – modelling house

An initial modelling house was firstly modelled for heating and cooling load simulation. The energy consumption simulation will be set followed passive house or zero carbon house standard. The total area of the two floors is 105 m^2. The U-values of the house elements depend on the Building regulation 2010 to build a low carbon modelling. There are 3 bedrooms inside with one living room, one kitchen and two toilets. It is based on the weather in Nottingham.

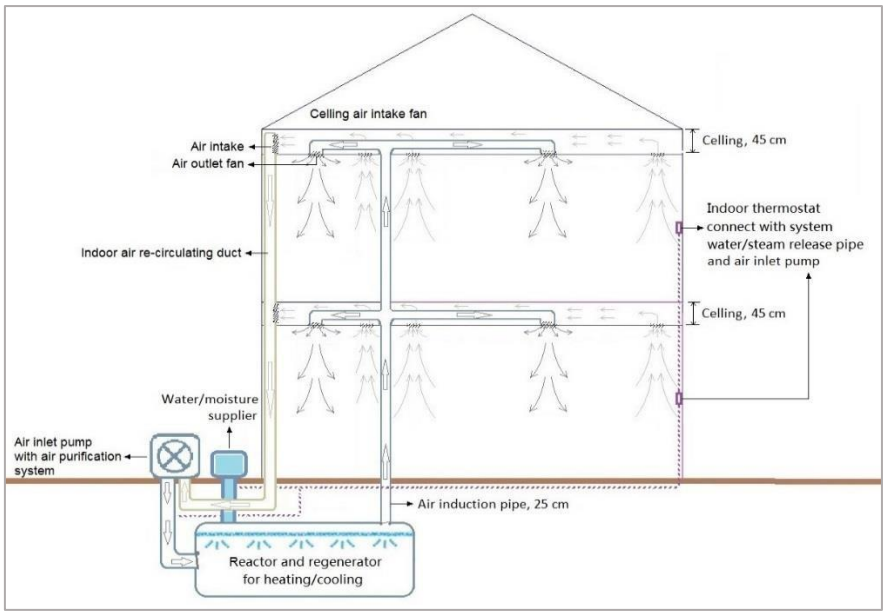

Figure 2. Modelling house with heating, cooling and induction system.

Modelling house energy simulation

In the novel thermochemical heating and cooling system, thermochemical salts will be used for both heating and cooling. The TES materials density will be shown as followed:

Table 1, Thermochemical heating material density and potential sizing.

Material	Heat storage density	Unit	Mass, ton
V-$MgSO_4$-$CaCl_2$	1173.5	kJ/kg	3.34
V-$MgCl_2$-$LiNO_3$	1000.8	kJ/kg	3.89
V-$MgSO_4$-LiCl	990.2	kJ/kg	3.94
V-$MgSO_4$-$LiNO_3$-$MgCl_2$	748.6	kJ/kg	5.21
V-$CaCl_2$	888.2	kJ/kg	4.39
V-$NaNO_3$	872.3	kJ/kg	8.15
V-Urea	727.85	kJ/kg	9.77

In the simulation house, total heating demand is 1091kWh/year or 11.5kWh/m^2/year, which equals to 3927.6MJ/year; total cooling demand is 1982.6kWh/year or 18.9kWh/m^2/year, which equals to 7137.2MJ/year.

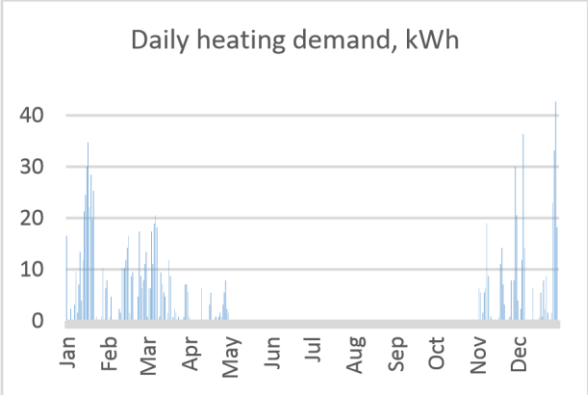

Figure 3. Daily heating demand.

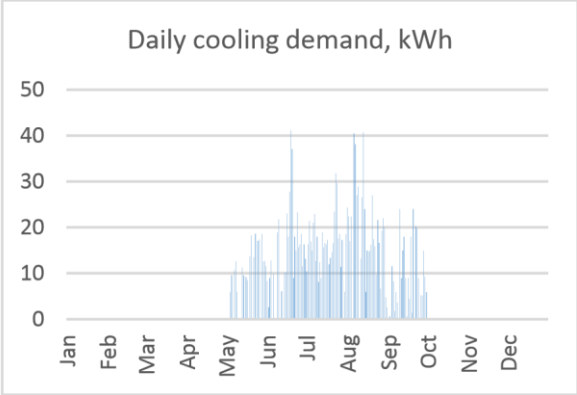

Figure 4. Daily cooling demand.

Materials and Characterization

TES materials have distinctive advantages: (1) TES materials have a high energy storage density, (2) high water or sorbate uptake, (3) the thermal losses during storage period nearly zero, (4) the required volume of material is much small, (5) variable charging temperature range, (6) low regeneration temperature, (7) non-toxic and no harmful to people and environment, (8) low-cost price per kW/h of energy stored with thermal stability.

In a TES system which uses salts as the thermochemical materials, deliquescence relative humidity (DRH) values are of interest, as they indicate the sorption properties of the THS materials. As comprehensively discussed in Ding and Riffat studies (Ding & Riffat, 2013; Posern & Kaps, 2010), presented in equation (a) is the process whereby the environment reaches the value of deliquescence relative humidity (DRH) or above. At this stage, deliquescence of the salt will occur since the inorganic salts will absorb moisture from humid air and form a solution. Meanwhile, when the value of the relative humidity is below the DRH, the salt may still absorb moist or water vapor, thus becoming hydrated, but it will not create solution. This is described in equation (b) as given (Ding & Riffat, 2013; Posern & Kaps, 2010).

$$\text{For RH} < \text{DRH: Salt (solid)} + H_2O\ \text{(gas)} \leftrightarrow \text{hydrated salt (solid)} \qquad \text{(a)}$$

$$\text{For RH} > \text{DRH: Salt (solid)} + H_2O\ \text{(gas)} \leftrightarrow \text{solution (liquid)} \qquad \text{(b)}$$

This thermochemical reaction is a reversible process. Thus, in both reactions the total amount of heat generated/absorbed during the reaction is given by the latent heat of condensation/evaporation and the thermochemical reaction during the water sorption/desorption process. The formation of salt solution in equation implies that a higher amount of heat is generated compared to reaction of equation during the sorption reaction due to the additional water sorption of the THS materials. Similarly, during desorption, if the salt used is in a liquid state, higher enthalpy change is required to regenerate the salt. Although higher energy is produced during the discharging (sorption) stage, the second process suffers from a disadvantage caused by the salt solution.

Another important property of the salts during the sorption reaction process is the hygrothermal stability. This property implies the rate of hydration reaction. Therefore, an innovative approach must be taken in order to optimize the performance of Thermochemical heat storage such that a balance between the enthalpy capacity and the hydration rate (discharging rate) process of the thermochemical materials could be reached. This includes exploring new composite materials with high energy density and have excellent sorption reaction properties and hygrothermal stability.

Composite materials synthesis

In Rammelberg et al. (Rammelberg, Osterland, Priehs, Opel, & Ruck, 2016) research, pure and mixed materials have been tested the stability in cycle during alternated dehydration and hydration reactions. It showed a poor cycle stability due to the over-hydration of the pure materials. However, if $CaCl_2$ was added into thermochemical materials, the mixture showed a better cycle stability and good performance. The hydrates $CaCl_2/MgCl_2$ mixture can form a tachyhydrite ($CaMg_2Cl_6.12H_2O$) phase to guarantee a good stability after 55 cycles without mass loss.

In this project, thermochemical heat storage materials (exothermic materials: LiCl, $CaCl_2$, $MgSO_4$) are chosen based on the potentially suited properties such as higher energy density, higher water uptake and lower regeneration temperature. The selected salts were combined with host matrix, such as vermiculite and activated carbon. Due to a lower cost and lower regeneration temperature, vermiculite was chosen as the host matrix in the project. The chemical reaction are shown below:

$$CaCl_2 + 6H_2O \rightarrow CaCl_2{\cdot}6H_2O + \text{Heat}$$

$$LiCl + 5H_2O \rightarrow LiCl{\cdot}5H_2O + \text{Heat}$$

$$MgSO_4 + 7H_2O \rightarrow MgSO_4{\cdot}7H_2O + \text{Heat}$$

Endothermic chemical reaction is an energy absorption process when the endothermic materials adsorb water. As one of the best endothermic materials, urea was discovered by Friedrich at the first time in 1828 and it presented that urea can be obtained from inorganic starting materials (Cohen & Cohen, 1996). It adsorbs water while absorbs great energy to show a cold surrounding temperature. In recent studies, there is no research shown on urea cooling system. The equation of urea hydrolysis is shown as followed:

$$(NH_2)_2CO + 2H_2O \xrightarrow{urease} (NH_4)_2CO_3 \text{ (Bundy, 2001)}$$

Nitrates such as sodium nitrate ($NaNO_3$), calcium nitrate ($Ca(NO_3)_2$), ammonium nitrate (NH_4NO_3) can absorb heat/energy when mixed with water. They are important endothermic materials which can be theoretically used for cooling. In Diarce et al. study, a mixture composed of sodium nitrate and urea for use as a phase change material (PCM) in thermal energy storage systems between 75 and 90 °C (Diarce, Corro-Martínez, Quant, Campos– Celador, & García–

Romero, 2016). The melting temperature was 85 °C with a latent melting enthalpy of 172 J/g and the mixture also showed sub-cooling during solidification.

Urea and Nitrate salts have the characteristic of water-cooled; however, there is few research did for the endothermic cooling system. Because of the hygroscopic of these endothermic materials, the influence of degradation and temperature shall be considered and tested in the future work.

Composite materials characterization

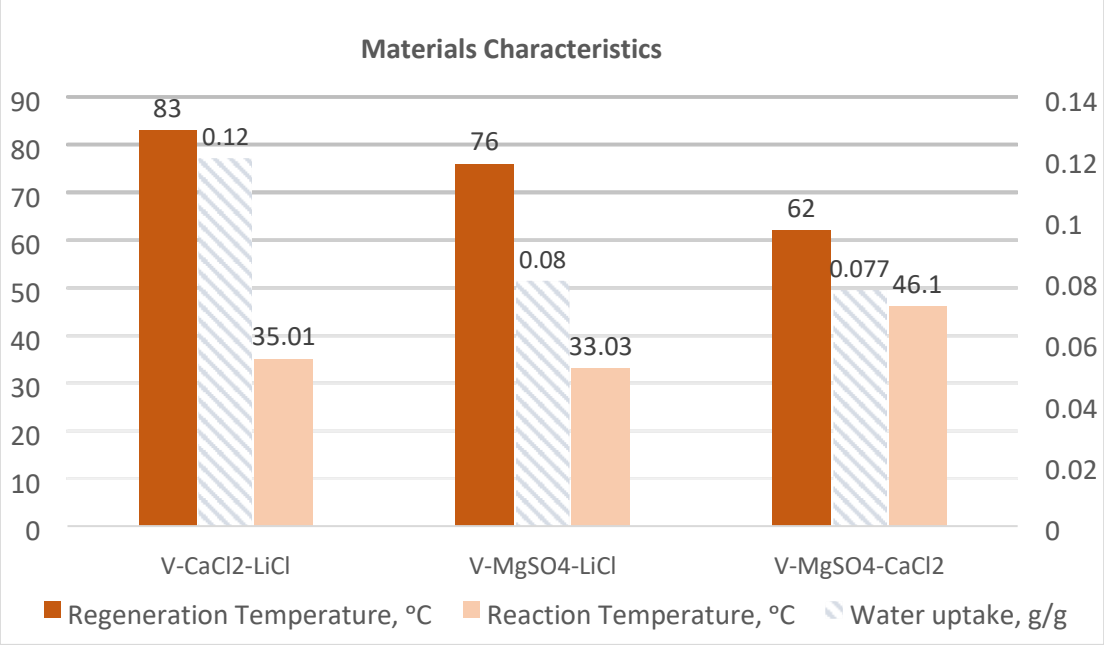

Figure 5. Different materials characteristics.

Material characterization allows the SIM samples to be compared for the best overall material in an open loop system can be determined. The increase in porosity of samples after impregnation shows the potential of salt impregnation of host matrices in open cycle THS systems (from SEM photos). V-$CaCl_2$-LiCl had the highest water uptake 0.12g/g whilst the other two had similar 0.08g/g. However, lowest regeneration temperature is an important characteristic, and also by considering reaction temperature, V-$MgSO_4$-$CaCl_2$ shows good potential for use in open THS systems.

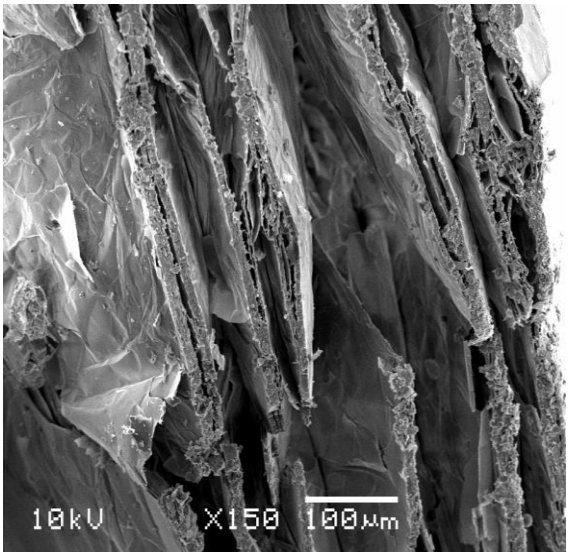

Figure 6. Vermiculite

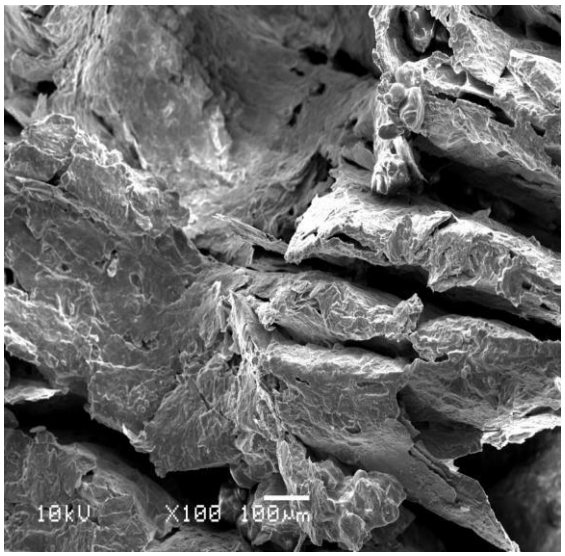

Figure 7. V-$MgSO_4$-LiCl

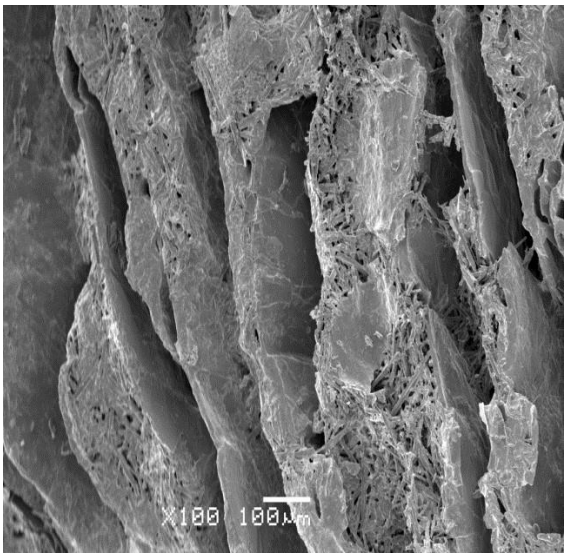

Figure 8. V-$CaCl_2$-LiCl

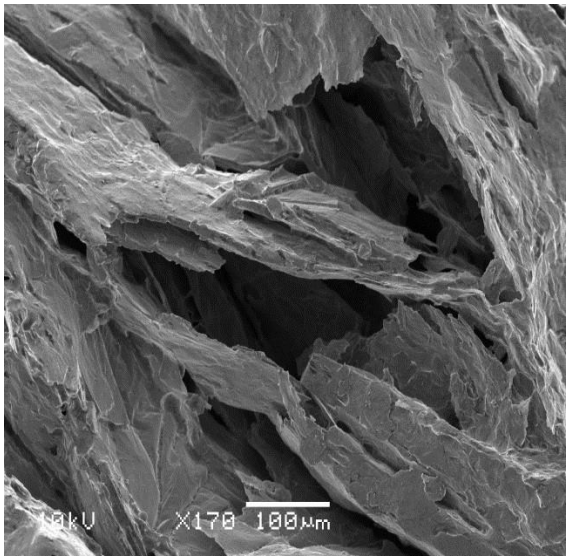

Figure 9. V-$CaCl_2$-$MgSO_4$

Conclusion and Future Work

Due to an increasing fossil fuel consumption and GHG emissions, thermochemical energy storage can be a promising advanced technology in addressing massive energy use for heating and cooling in building application, because of the lower heat loss, higher energy density of the materials, more efficient and environmentally friendly. In the project, we used different high energy density storage salts (e.g. $CaCl_2$, $MgSO_4$, LiCl, $MgCl_2$) with vermiculite as the host matrix. In this study, it characterize different composite to find better performing materials with higher energy density, lower heat loss, lower regeneration temperature, higher temperature lift in reaction process and higher system efficient.

The results of this study showed the following:

- The initial simulation showed a less energy demand (3073kWh/year) with the estimated volume of each TES materials;
- The impregnation of the TES materials can increase porosity of the host matrix;
- The reaction temperature and the regeneration temperature showed that V-$MgSO_4$-

  $CaCl_2$ displays optimal characteristics for the potential of using in an open TES system.

Future research will focus on:

- testing and analysing different salts mixture structure and performance;
- finding better way for materials reuse for long-life cycle;
- filling the gap between energy demand and supply;
- optimising thermochemical energy storage system for both heating and cooling with solar thermal collector driven.

ACKNOWLEDGEMENTS

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Use and Re-Use

AN INVESTIGATION OF MUNICIPAL SOLID WASTE GENERATION AND CHARACTERISTICS IN GHANA

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Keywords: Municipal solid waste, solid waste generation, solid waste characteristics, Ghana

Abstract

Accurate prediction of municipal solid waste (MSW) generation and knowledge of the waste characteristics provide the basic data on which a waste management system is planned, designed, and operated. However, reliable data on MSW generation and characteristics in most developing countries is absent. This paper examines MSW generation and characteristics in Ghana. The data was obtained from secondary data sources, using qualitative and quantitative research methods, through documentary analysis and content analysis of published literature and official documents. The secondary data obtained for the study is deemed valid, reliable, and accurate since the research design and methodology and data analysis of the documents viewed followed research protocols. The investigation found out that the MSW generation rates across Ghana, irrespective of the socioeconomic considerations range between 0.2 and 0.9 kg/person/day. The MSW composition in Ghana is heterogeneous with different chemical properties; the household MSW composition in Ghana is more organic (60%), 25% recyclables, and 15% miscellaneous. The high organic waste component of the MSW stream in Ghana has resulted in high moisture content (above 50% on average) of the MSW. This organic fraction is an important component, not only because it constitutes a significant portion of the MSW stream in Ghana, but also because of its potentially adverse impact on public health and environmental quality if not properly treated and/or disposed of. The impact of organic MSW on environmental quality takes the form of foul odours, unsightliness and leachate from open dumps, especially after rainfall, and emission of harmful gases. Unless an organic waste is appropriately treated and disposed of, its adverse impact will continue until it has fully decomposed or otherwise stabilised. Therefore, the study recommends the adoption of appropriate management technologies to ameliorate the impact of MSW in the country and other developing countries.

INTRODUCTION

The growing world population, economic growth, rapid urbanisation, and the rise of human living standards, especially in developing countries are resulting in high resource use in response to changing lifestyles. The accompanying increase in consumption is rising wastes generation far beyond the management ability of most municipal authorities in developing countries [1]. As a result, waste disposal is an immediate and critical issue for many developing countries now as

ineffective or irresponsible disposal of solid waste (SW) pollutes the environment and pose health risk to the public [2].

The current state of municipal solid waste management (MSWM) in Ghana, for instance, leaves much to be desired. Less than 40% of urban residents are served with solid waste collection (SWC) services [3]–[5]. The traditionally applied methods of dealing with waste have been unsuccessful, and the resulting contamination of water and land has led to growing concern over solid waste management (SWM) in the country [6], [7].

Various pollution (air, soil, water, and landscape) due to improper waste disposal would not only affect the natural environment but also exposed the community to various diseases. An example is the contamination of surface and ground water supplies from indiscriminate dumping of wastes in most developing countries [8]–[10]. This occurs through leachate from MSW disposal sites and run-off that carry MSW into water bodies, which lead to rising levels of biochemical oxygen demand (BOD) in watercourses, and the presence of microbial contaminants [11]. It takes only a small amount of leachate to contaminate a large volume of groundwater, which in turn can contaminate and affect biodiversity and enter the food chains [12]–[14].

Open dumps, which are prominent in in Ghana and other developing countries, attract vermin and scavenging animals and provide food and habitat for disease vectors such as rats and mosquitoes. Clogging of storm drains and creation of stagnant water due to the choked drains (as illustrated in plate 1) are other problems of improper MSW disposal in urban areas in most developing countries and is the prime cause of flooding in the rainy season in cities in Ghana.

Plate 1: A choked drain in Accra, Ghana, after a rain

In addition, uncontrolled burning of MSW, which is wide spread in most developing countries, contributes significantly to urban air pollution. MSW contains considerable hazardous components and the open MSW burning in urban areas cause direct exposure of hazardous materials to citizens [15]. Globally, efforts are being made to control greenhouse gas (GHG) emissions from various sources, and the waste sector is one of them [16].

Thus, the objective of this paper is to investigate MSW generation and characteristics in Ghana reported in literature and official documents, with the aim of identifying possible interventions to ameliorate the impacts of MSW in Ghana and other developing countries.

LITERATURE REVIEW

MSW generation refers to the generation of any solid, non-hazardous substance or object within an urban area, excluding wastewater sludge [17]. The main constituents of MSW generated in general are similar throughout the world, but the quantity generated, the density and the proportion of streams vary widely from country to country, depending largely on the level of income and lifestyle, culture and tradition, geographic location and dominant weather conditions [18]–[21].

Sound waste management and optimisation of resource recovery from waste require reliable data on the generation rates and characteristics of waste [22]–[24], because the accurate prediction of MSW generation and knowledge of the waste characteristics provide the basic data on which a waste management system is planned, designed, and operated [25]–[29]. However, reliable data on MSW generation and characteristics that will inform effective planning for waste management in most developing countries is absent [25].

The World Bank (2012) indicates that the current global MSW generation levels are roughly 1.3 billion tonnes per year, and are expected to increase to approximately 2.2 billion tons per year by 2025 (see tables 1 and 2). This would signify a major increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next five years. Waste management problems in most developing countries are likely to worsen, if appropriate plans are not put in place to effectively deal with this galloping generation rate.

Table 1: Waste generation per capita by regions

Region	Waste Generation Per Capita (kg/capita/day)		
	Lower Boundary	Upper Boundary	Average
Africa Region (AFR)	0.09	3.0	0.65
East Asia and Pacific region (EAP)	0.44	4.3	0.95

Europe and Central Asia region (ECA)	0.29	2.1	1.1
Latin America and the Caribbean region (LCR)	0.11	5.5	1.1
The Middle East and North Africa region (MENA)	0.16	5.7	1.1
Organisation for Economic Co-operation and Development (OECD)	1.10	3.7	2.2
South Asia region (SAR)	0.12	5.1	0.45

Source: [31]

Table 2: Waste generation projections for 2025 by regions

Region	**Current Available data**			**Projection for 2025**			
	Total Urban Population (millions)	Urban Waste Generation		Projected Population		Projected Urban Waste	
		Per Capita (kg/capita /day)	Total (tons/day)	Total Population (millions)	Urban Population (millions)	Per Capita (kg/capita /day)	Total (tons/day)
AFR	260	0.65	169,119	1,152	518	0.85	441,840
EAP	777	0.95	738958	2124	1229	1.5	1,865,379
ECA	227	1.1	254,389	339	239	1.5	354.810
LCR	399	1.1	437,545	681	466	1.6	728,392
MENA	162	1.1	173,545	379	257	1.43	369,320
OECD	729	2.2	1,566,286	1,031	842	2.1	1,742,417
SAR	426	0.45	192,410	1,938	734	0.77	567,545
Total	2,980	1.2	3,532,252	7,644	4,285	1.4	6,069,703

Source: [31]

Eiselt and Marianov (2015) note that the per capita waste generation rates in many developing countries have now crossed the one kilogram per day mark, which is a worrying trend because most municipal authorities do not have the capacity to effectively manage this waste. The waste generation in sub-Saharan Africa is nearly 62 million tons per year, though per capita waste generation is generally low in the region, the generation spans a wide range, from 0.09 to 3.0 kg per person per day with an average of 0.65 kg/capita/day [33].

Similarly, the waste generation for the Middle East and North Africa (MENA) is in tune with the rest of the world as the SW generation in MENA is 63 million tons per year and the per capita waste generation is 0.16 to 5.7 kg per person per day and has an average of 1.1 kg/capita/day [31]. This exponential increase in the waste generation comes with its management challenges, especially for developing countries where there are competing interests on the municipal budget. However,

with the majority of the world's population now urbanized, MSW generation rates are likely to increase further, particularly in developing countries, where more and more people are migrating from rural areas to cities [34], [35].

Currently, high-income countries produce the most waste per capita, while low-income countries produce the least SW per capita [36]. This is not only because in low-income countries, there is less commercial and industrial activities, resulting in lower waste generation rates, but also because there is an overall correlation between the generation of MSW and wealth (Gross Domestic Product) [37], as illustrated in Table 3.

Table 3: Waste generation per capita by Income Levels

Income level	**Waste Generation Per Capita (Kg/capita/day)**		
	Lower Boundary	**Upper Boundary**	**Average**
High	0.70	14	2.1
Upper Middle	0.11	5.5	1.2
Lower Middle	0.16	5.3	0.79
Lower	0.09	4.3	0.60

Source: [31]

Furthermore, Like MSW generation, MSW composition is equally influenced by many factors, such as level of economic development, cultural norms, geographical location, energy sources, and climate [38], [39]. Oteng-Ababio (2014) supports this in his assertion that, as a country urbanizes, and populations become wealthier, consumption of inorganic materials (such as plastics, paper, and aluminium) increases, while the relative organic fraction decreases. This is event in the high volumes of inorganic waste generated in developed countries and the high organic waste generated in developing countries.

In general, low-income countries have a high percentage (between 40 to 85%) of organic matter in the urban waste stream, while paper, plastic, glass, and metal fractions dominate the waste stream of high-income countries [41], [42]. For instance, the East Asia and the Pacific Region has the highest fraction of organic waste (62%) compared to OECD countries, which have the least (27%) [43].

On the other hand, the amount of paper, glass, and metals found in the MSW stream are the highest in OECD countries (32%, 7%, and 6%, respectively) and lowest in the South Asia Region (4% for paper and 1% for both glass and metals) [43]. Similarly, sub-Saharan Africa also has the highest fraction of MSW being organics (57%) [31]. Table 4 indicates the MSW composition and generation rate in some selected cities in Africa. Only cities in Ghana have miscellaneous MSW fraction, probably due to the non-segregation of waste at the point of generation.

Table 4: MSW composition and generation rates in some selected cities in Africa

City	Country	Per capita GDP (US$) [44]	Population of city (million)	Genera-tion rate kg/p/day	Organics (%)	Inorganic (%)	Inert (%)	Miscellaneous (%)	Source
Accra	Ghana		1.96	0.74	65.8	25.7	5.2	4.1	[25]
Kumasi		1,513.5	1.47	0.75	48.4	33.2	10.7	7.8	
tamale			0.36	0.33	58.6	23.7	4.5	3.4	
Lagos	Nigeria	2,178.0	9.00	0.5	53	39	8		[45]
Freetown	Sierra Leone	496.0	0.80	0.56	59.2	10.2	19.9		[46]
Nairobi	Kenya	1,455.4	2.75	0.6	65	21	14		[47]
Cape Town	South Africa	5,273.6	3.43	0.7 – 1.3	47	32	21		[48]
Cairo	Egypt	3,514.5	7.73	1.3	56	34.7	9.4		[49]

Another important property of MSW is its moisture content. The moisture content of SW is expressed as the mass of moisture per unit mass of water or dry materials [50]–[52]. It is a very important factor that influences decisions on MSW collection and transportation [53]. Transfer of moisture takes place in garbage bins and collector trucks during storage and transportation of MSW, therefore, the moisture contents of various components change with time [54].

Moisture content equally plays a key role in the degradation and treatment of MSW. For example, in composting, moisture content affects the magnitude of heat generation, which can affect the quality of compost [55]–[57]. In a landfill, leachate is formed when the refuse moisture content exceeds its field capacity [58]. Also, many researchers have observed that high moisture content is a major hindrance in the field of thermal conversion of waste-toenergy (WTE) technologies [59], [60], because the moisture content influences the calorific value of the waste to be incinerated.

METHODS

Data on MSW generation rates and characteristics in Ghana, such as composition, moisture content and calorific value were obtained, using qualitative and quantitative research methods, through documentary view of official reports and journal publications. The focus of the

documentary view was on the content analysis of the quantitative data on MSW generation rates and characteristics in the documents viewed. The content analysis enabled the researchers to sift through large volumes of data with relative ease in a systematic manner [61]. The researchers depended on the secondary data, because the data was available and thus, saved time and money which otherwise would have been used to collect primary data as no field trips and surveys were involved [62]. The secondary data obtained for the study is deemed valid, reliable, and accurate since the research design and methodology, and data analysis of the documents viewed followed research protocols; the information was relevant and appropriate to the study objective; and because there was consistency in the data in the documents viewed [63]–[65].

RESULTS AND DISCUSSION

MSW generation in Ghana

The MSW generation rates across Ghana, irrespective of the socioeconomic considerations range between 0.2 and 0.9 kg per person per day [25], [40], [66], as shown in table 5. The increasing MSW generation in the country is attributable to the increasing urban population. Ghana's rapid urbanisation has led to many sustainable development challenges, particularly regarding sanitation, including SWM and transportation infrastructure.

The proportion of the country's population living in towns, as officially defined (any settlement with at least 5,000 people), has increased rapidly over the years as shown table 6. The percentage of urban dwellers before independence in 1955 was 19.1%, it rose drastically to 40.1% by the end of the 19th century. However, in recent decades, the country has experienced steady urbanisation with the current urban population being 52.7%.

Table 5: MSW generation in the regional capitals of Ghana

Regional Capital	2017 Population (based on 2010 Census)	High-class income areas (kg/p/day)	Middle - class income area (kg/p/day)	Low - class income areas (kg/p/day)	Average generation rate (kg/p/day)	Total Generation (population/ tons)
Accra	2237933	0.86	0.73	0.62	0.74	1656
Bolgatanga	147836	0.31	0.20	0.20	0.21	31
Cape Coast	205674	0.74	0.69	0.58	0.67	138
Ho	321544	0.34	0.33	0.27	0.31	100
Koforidua	213915	0.80	0.54	0.48	0.61	130
Kumasi	2425639	0.63	0.73	0.86	0.75	1819
Sunyani	144599	0.52	0.49	0.47	0.49	71
Tamale	446080	0.38	0.27	0.36	0.33	147
Takoradi	648940	0.76	0.68	0.65	0.70	454

Wa	128873	0.30	0.23	0.21	0.25	32
Average	691605	0.56	0.49	0.47	0.51	458

Source: modified from [25], [66]

Table 6: Urban population percentages between 1955 and 2018 in Ghana

Year	Total Population	Urban population (%)
2018	29,463,643	52.7
2017	28,656,723	54.2
2016	28,033,375	53.7
2015	27,409,893	53.2
2010	24,317,734	50.6
2005	21,389,514	47.3
2000	18,824,994	43.9
1995	16,760,991	40.1
1990	14,628,260	36.4
1985	12,716,238	32.9
1980	10,802,025	31.2
1975	9,831,409	30
1970	8,596,977	29
1965	7,710,547	26.1
1960	6,652,285	23.3
1955	5,680,406	19.1

Source: [67]

MSW composition in Ghana

The MSW composition in Ghana is heterogeneous and mixed (non-degradable materials and degradable components) with different chemical properties. The household MSW composition in Ghana is more organic (60%), 25% recyclables, and 13% miscellaneous (table 7 indicates the waste composition in Ghana). The high proportion of miscellaneous MSW (5% on average) calls for the separation of waste at the generation point.

The high organic waste component of the MSW stream in Ghana has resulted in high moisture content (above 50% on average) of the MSW, which conforms with the waste stream in other developing countries [68]–[70]. Table 8 outlines the chemical composition of the household waste in Ghana by different researchers.

Table 7: Household Waste Composition and generation in Ghana

Component	High class income areas (%)	Middle class income areas (%)	Low class income areas (%)	Average (%)
Yard waste (leaves)	17.334	7.562	8.915	11.270
Animal dropping/manure (Grass)	0.176	0.379	0.291	0.282
Wood (Branches)	1.301	1.346	1.282	1.310
News paper	0.674	0.388	0.414	0.492
Cardboard	3.223	3.215	2.233	2.890
Office paper	0.605	0.445	0.541	0.530
Tissue paper	1.148	1.520	1.677	1.448
HDPE - Translucent	3.075	2.751	3.418	3.081
HDPE - Pigmented	2.071	3.628	5.358	3.686
PET	3.315	3.297	2.104	2.905
PP rigid	1.554	1.521	1.126	1.400
PS	0.606	0.538	0.583	0.576
PVC	0.554	0.618	0.247	0.473
Other plastics	2.402	1.983	2.153	2.179
Ferrous Can	1.721	1.319	2.108	1.716
Ferrous metals	1.060	1.575	0.530	1.055
Plain glass	0.846	1.072	0.588	0.835
Coloured glass	2.864	1.991	0.00	1.618
Leather & Rubber	1.012	1.171	1.035	1.073
Food waste	44.201	50.595	49.358	48.051
Textiles	0.528	1.149	1.799	1.159
Miscellaneous	9.73	11.937	14.24	11.969
total	100	100	100	100

HDPE = High-density polyethylene, PET = polyethylene terephthalate, PP = Polypropylene, PS = Polystyrene, PVC = Polyvinyl chloride.
Source: modified from [25]

Table 8: Chemical composition of household wastes in Ghana

Property	Kuleape, et al., 2014	Fobil, et al., 2005	Adu & Lohmueller, 2012
Calorific value (kJ/kg)	$1.39 \times 10^4 – 2.99 \times 10^4$	$1.4 \times 10^4 – 2.0 \times 10^4$	1.69×10^4
Moisture Content (%)	25 - 76	40 - 60	50
Ash Content (%)	2.2 - 19	nd	nd
Volatile Solids (%)	31 - 88	nd	nd
Density (kg/m^3)	nd	$5.3 \times 10^2 – 5.4 \times 10^2$	nd

*nd = not determined

The MSW stream in many developing countries, including Ghana is more organic. The organic fraction is an important component, not only because it constitutes a significant portion of the MSW stream in Ghana and other developing countries, but also because of its potentially adverse impact on public health and environmental quality if not properly treated and/or disposed. A major adverse impact is its attraction of rodents and vector insects for which it provides food and shelter [74]. The impact of organic MSW on environmental quality takes the form of foul odours, unsightliness and leachate from open dumps, especially after rainfall, and emission of harmful gases [75]. These impacts are usually not limited only to the disposal site, they pervade the neighbouring area to the site and wherever the wastes are generated, spread, or accumulated. Unless an organic waste is appropriately treated and disposed of, its adverse impact will continue until it has fully decomposed or otherwise stabilised.

CONCLUSION

The study indicates that the global MSW generation rates are rising exponentially due to the increasing global population and improvement in living standards, and that the increasing waste generation rates is further exacerbating the problems of MSWM in developing countries such as Ghana, which are currently struggling with ineffective SWM systems due to the lack of the enabling environment for effective waste management. Organic fraction forms the highest (over 50%) of the MSW stream in Ghana and other developing countries.

The organic fraction is an important component, not only because it constitutes a significant portion of the MSW stream in Ghana and other developing countries, but also because of its potentially adverse impact on public health and environmental quality if not properly treated

and/or disposed. This beckon the adoption of appropriate management technologies to ameliorate the impact of MSW in Ghana and other developing countries.

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GREEN CONSCIOUSNESS OF HOUSEHOLD OWNERS IN SOUTH AFRICA

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Keywords: Energy wastage, Green consciousness, Recycling, Water wastage.

Abstract

The planet earth has been damaged by people because our industrial systems left us with no choice. High-rise buildings, industrial factories, and power plants were built long before the consequences were known; now concerns regarding global warming, climate change and environmental pollution have been on the rise. The primary aim of this study was to determine the green consciousness of household owners within South Africa. The research was to investigate whether individuals are aware of the environmental damage caused by humans; the actions that are available to reduce their carbon footprint at home; and lastly, to determine whether the running costs associated with energy and water wastage from households could be reduced by creating the awareness and implementation of these actions. A closed and open-ended questionnaire was distributed to 40 household owners within Nelson Mandela Bay, and a response rate of 85% was achieved. The reason for this approach was that the results could easily and accurately be analysed. The findings revealed that most people are aware of the impact that humans have on the environment, and the possible saving on household running costs from going green; however, the respondents tend to lack the motivation to participate in actions such as recycling and the reuse of grey water. This is due to a lack of education concerning the benefits of such actions, as well as the lack of facilities available in South Africa to facilitate the processes involved in recycling and the reuse of grey water. Although, recycling and water saving techniques undertaken by households in South Africa proved to be low; the majority of the respondents in this study indicated that they have adopted most of the energy saving techniques in their household.

INTRODUCTION

A lack of environmental concern by household owners in South Africa (RSA) have led to excess energy and water consumption, which has an effect on the running costs of households. A wide variety of green solutions exist that individuals could implement to protect the environment and reduce consumption (Manaktola & Jauhari, 2007: 363). Nonetheless, Tantawi, O'Shaughnessy, Gad & Ragheb (2009: 31) contend that the resolution of environmental problems depends more on the attitudes of the general public than on the knowledge of experts. According to Manaktola & Jauhari (2007: 363), these solutions are beneficial in that they may save households money by reducing consumption, and will ultimately reduce the effect of carbon footprint. However, some of these drastic changes may cost individuals more money in the short term, but will aid in saving

the environment and reduce household costs in the long run (Manaktola & Jauhari, 2007: 363). Against this background, this study investigates the adequacy and performance of sustainable techniques adopted by household owners in South Africa. Specifically, this research will examine whether individuals are aware of the environmental damage caused by humans; the actions that are available to reduce their carbon footprint at home; the costs associated with these actions and lastly, to determine whether the running costs, energy and water wastage from households could be reduced due to awareness and implementation of these actions.

LITERATURE REVIEW

Green consciousness, sustainability and going green

According to Beer (2013:9), green consciousness describes a state of mind which influences a person's knowledge, attitude or behaviour towards the protection of the environment. Sustainable development can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Viviers, 2009: 31). The term going green can be referred to as the actions undertaken by individuals to protect the quality and continuity of life and the environment (Viviers, 2009:
30).

Energy is wasted in households

Energy inefficiency occurs when energy is wasted in its distribution or its use. Biton (2006: 1) argued that unnecessary energy usage means wasted fossil fuels, which are non-renewable materials that are difficult to extract and produce. The process of extracting these fuels is detrimental to the environment by polluting the air and surrounding water sources (Biton, 2006: 1). Furthermore, wasted energy is wasted money (Biton, 2006: 1). According to Manaktola and Jauhari (2007: 363), a lack of environmental concern has led to energy wastage in many traditional homes.

Excessive waste (garbage) generated by households

In South Africa, there is an absence of a strong government commitment to regulate the disposal of domestic waste. The general tendency in cities is for people to dispose of their domestic waste as quickly and conveniently as possible. This often leads to large piles of solid wastes being dumped in the outskirts, causing waste-contaminated rivers which form an unpleasant habitat for disease and organisms to develop (Kamara, 2006: 4). According to Halvorsen (2012: 18), the solution to reduce these problems is household recycling. Household recycling relies heavily on voluntary contributions from individual households. Economic incentives and regulations are used by some countries to stimulate this effort; although, in South Africa, few or no incentives exist. Despite this, households make considerable efforts to recycle, even when no economic incentives exist. This implies that non-economic motivations are important for household recycling activities (Halvorsen, 2012: 18).

Excessive water usage in households

The scarcity and misuse of water represented a serious threat to sustainable development. The consumption still exceeds the rate of replenishment, and its wasteful uses have created a major environmental problem. Therefore, saving water is a key action, with a significant impact on the different areas of sustainability: economic, political, environmental and social (Sarabia-Sánchez & Rodríguez-Sánchez, 2013: 116). A great proportion of residential water users do not require strictly drinking water quality. Therefore, it is possible to use water with a lower quality (grey water) for such uses (Oviedo-Ocaña *et al.,* 2017: 1). Grey water can be defined as wastewater from baths, showers, sinks and washing machines. This grey water can be recycled and accounts for about 60% of the outflow from homes (Madungwe & Sakuringwa, 2007: 1234).

Household running costs are high

The cost of consuming resources in households is increasing, both economically and ecologically. Homeowners therefore need to find ways to reduce their consumption (Makonin, Ellert, Bajic & Popowich, 2016: 1). Some parts of South Africa are currently experiencing a drought; therefore, the scarcity and cost of water has increased. Water availability has become a matter of concern all over the world. Society must shift towards the goal of efficient and appropriate water use. Energy use plays a significant role in the running costs of households. Homeowners therefore need to reduce the consumption, by turning off electrical appliances and lights when leaving the room, to completely redesigning the way of life around these solutions to save the owners money (Manaktola & Jauhari, 2007: 363).

RESEARCH

Research methodology

The quantitative method was adopted to achieve the aim and objectives of the study. de Vos (2005: 137) opined that in quantitative design, the empirical data is in the form of numerical data. Quantitative research measures objective facts, where the focus is on variables and the key is reliability (de Vos, 2005: 137). For the purpose of fulfilling the aims of this study, non-probability sampling was used due to "the relevance of the research topic rather than the representativeness which determines the way in which the people to be studied are selected" (Flick, 1998: 220). The non-probability method does not use a mathematical random process to select sampling elements rather; it refers to the selection of specific participants who are willing to take part. The total sample population included in the study was heterogeneous and comprised approximately 40 participants. The sample encompassed individuals that reside in the Port Elizabeth region, South Africa. To get a variety of household types and sizes, various suburbs were selected within Port Elizabeth. The suburbs selected included: Walmer, Summerstrand, Bluewater Bay, and Mount Croix. 10 participants were selected from each suburb to fill out the questionnaire. The survey was hand delivered to the 40 participants and a total of 34 duly completed questionnaires were received, providing an 85% response rate. The questionnaire was designed based on the main problem, the sub-problems and the literature review of this study. The first 4 questions of the

questionnaire referred to biographical questions. These questions were structured to determine the participant's gender, home language, household size and the period they have lived in that location. The participants were then asked to record their average expenditure on water and electricity per month, and the number of black bags of waste that the household produces per week. After which the following questions were structured in such a way that the Likert scale (LS) could be applied. In addition, the dichotomous style yes or no questions incorporated with an unsure option was also included in the questionnaire. The LS that was used in this research included two types; the scale of 'minor to major' incorporated with a 'Does Not' option and the scale of 'never to always'. A scale of 1 to 5 was used for these questions, and is explained prior to each section of the questionnaire. The quantitative data was encoded using the Statistical Package for the Social Sciences (SPSS), and results were analysed statistically using the descriptive statistics.

RESEARCH FINDINGS

Table 4.1 presents the responses with regard to the level of environmental awareness within household owners in RSA. The participants were asked to record their perspective of the following contentions by rating them on a scale of 1 (minor) to 5 (major), with an additional point 'does not'. Given that there are effectively six points on the scale, the mean scores (MSs) range between a minimum value of 0.00 and a maximum of 5.00, the midpoint being 2.50. It is worth noting that all the MSs are > 2.50, which gives a clear indication that in general these factors contributed more of major than a minor extent to enhancing the level of environmental awareness within household owners. The hierarchy of the descriptive analysis reveals that recycling positively impacts on the environment had the highest MS and ranked first, followed by human activity is responsible for the degenerating environment (4.44), and green buildings positively impact on the environment (4.42). However, all the MSs > 4.17 ≤ 5.00, which indicates that the extent to which the factors enhanced the level of environmental awareness within household owners can be deemed to be between a near major extent to a major extent / major extent.

Table 4.1: Environmental awareness

Contention	**Frequency (%)**							**MS**	**Rank**
	Un-sure	**Does not**	**Minor ……Major**						
			1	**2**	**3**	**4**	**5**		
Recycling positively impacts on the environment	0.0	2.9	2.9	0.0	5.9	11.8	76.5	4.64	1
Human activity is responsible for the degenerating environment	0.0	0.0	0.0	0.0	11.8	32.6	55.9	4.44	2
Green buildings positively impact on the environment	8.8	0.00	2.9	0.0	11.8	17.7	58.8	4.42	3

Going green can save money	0.0	0.00	2.9	5.9	5.9	23.5	61.8	4.35	4
Natural resources are diminishing	2.9	0.00	0.0	0.0	17.7	32.4	47.1	4.30	5
Global warming is occurring	2.9	0.00	0.0	5.9	20.6	11.8	58.8	4.27	6
The environment is degenerating	0.0	0.00	0.0	2.9	17.7	29.4	50.0	4.26	7

Energy usage associated with households

Table 4.2 below present the responses with regard to the extent to which the respondents undertake the energy saving measures available within households in RSA. The participants were asked to record their level of frequency by rating the following statements on a scale of 1 (never) to 5 (always). Given that there are five points on the scale, the mean scores (MSs) range between a minimum value of 1.00 and a maximum of 5.00, the midpoint being 3.00. It is worth noting that all the MSs are > 3.00. It is clear that the MS for turning off electrical appliances < MS for turning off lights. Turning off electrical appliances when not in use has a MS of 3.85, which indicates that the frequency of the respondents may be deemed between sometimes to often / often. The MS of 4.29 for turning off lights indicates a frequency of between often to always / always. These findings are in alignment with the literature and corroborated by Manaktola & Jauhari (2007: 363) who opined that energy consumption in households may be significantly reduced by turning off electrical appliances and lights when leaving the room, to completely redesigning the way of life around these solutions to save the owners money.

Table 4.2: Energy saving measures

State	**Frequency (%)**						
		1	**2**	**3**	**4**	**5**	
	Unsure	**Never**	**Rarely**	**Sometimes**	**Often**	**Always**	**Mean**
Turning off lights in our household when leaving a room or when they not needed	0.0	0.0	0.0	23.5	23.5	52.9	4.29

Turning off electrical appliances in our household when leaving a room or when they are not in use	0.0	5.9	5.9	23.5	26.5	38.2	3.85

Table 4.3 presents the responses with regard to whether the participants have the following energy saving measures implemented in their home or not. It may be seen that only the use of solar energy had a predominantly negative result, with 91.2% of the respondents recording that they did not make use of this energy saving measure. The remaining states all had predominantly positive results; the use of a geyser time switch (61.8%); natural lighting (73.5%); LED light bulbs (70.6%), and the awareness of kWh electricity usage of 58.8% all recorded a positive result.

Table 4.3: Energy saving measures

State	**Frequency (%)**		
	Yes	**No**	**Unsure**
Our home has a geyser time switch that minimises the duration of heating	61.8	26.5	11.8
Our home makes use of solar energy	8.8	91.2	0.0
Our home makes use of natural lighting and therefore we do not turn the lights on during the day	73.5	26.5	0.0
Our home has LED (energy saving) light bulbs	70.6	23.5	5.9
I / My family is aware of our kWh (kilowatt hours) electricity usage	58.8	20.6	20.6

Garbage and recycling

Table 4.4 presents the responses with regard to the extent to which the participants undertook the following actions; these actions are ways in which households could reduce the amount of garbage produced. The participants were asked to record their participation in the following actions by rating them on a scale of 1 (minor) to 5 (major), with an additional point 'does not'. It is worth noting that majority of the MSs are < 2.50, which gives an indication that in general these actions are not a priority in most households.

The action of minimising household waste by avoiding disposable products whenever possible scored a MS of 2.50, indicating that the participants' opinion in respect of this action may be deemed neutral. Participation in minimising the amount of plastic in the household and recycle e.g. plastic bottles and glass, and cardboard may be seen as between minor to a near minor extent / near minor extent since the MSs are > 1.67 ≤ 2.50. . The action creating compost in the household may be deemed to be between minor to near minor extent since the MS is > 0.83 ≤ 1.67.

Table 4.4: Actions to reduce household garbage

Action	Frequency (%)							MS	Rank
	Un-sure	Does not	Minor ……Major						
			1	2	3	4	5		
Minimise household waste by avoiding disposable products whenever possible	0.0	11.8	11.8	17.7	32.4	2.9	17.7	2.50	1
Minimise the amount of plastic brought into the household	2.9	20.6	14.7	17.7	26.5	8.8	8.8	2.15	2
Recycle e.g. plastic bottles and glass, and cardboard	2.9	35.3	14.7	20.6	11.8	5.9	11.8	1.74	3
Create compost	2.9	44.1	26.5	8.8	5.9	5.9	5.9	1.18	4

The participants were asked in question 10.2 to state the materials they recycle. 11 of the 34 respondents answered this question, providing a 33% response rate. The materials mostly recycled by the respondents were that of glass and plastic and to a lesser extent paper and metal. None of the participants were active in recycling electronic waste (eWaste).

Water usage associated with households

Table 4.4 presents the responses with regard to whether the participants have the following water saving measures implemented in their home or not. The majority of the respondents indicated that their participation in water saving measures was low; with only the awareness of the kilolitres of water used (52.9%), and the attempt to keep water use as low as possible (97.1%) producing positive results. The remaining statements produced predominantly negative results from the respondents; grey water systems installed (61.8%); water tanks to collect rainwater (55.9%); use of borehole water (79.4%), and the reuse of grey water as much as possible (55.9%) all recording 'No'.

Table 4.5: water saving measures

State	Frequency (%)		
	Yes	No	Unsure
Our home has grey water systems installed	5.9	61.8	32.4
Our home has water tanks to collect rainwater	41.2	55.9	2.9

Our home makes use of borehole water	8.8	79.4	11.8
Our home reuses grey water as much as possible	17.7	55.9	26.5
I / My family is aware of how much kilolitres of water we use	52.9	35.3	11.8
I / My family attempts to keep our water usage as low as possible	97.1	0.0	2.9

Running costs associated with households

Various interventions exist that can help reduce the running costs associated with households. These interventions will only be helpful if the households' owners / residents actually make use of them. Table 4.6 presents the responses with regard to the extent to which the participants agree that the following interventions can help reduce the running costs associated with households. The participants were asked to record their perspective of the following interventions by rating them on a scale of 1 (minor) to 5 (major), with an additional point 'does not'. It can be seen that all the MSs are > 2.50, which gives a clear indication that in general these factors contributed more of major than a minor extent to reducing the running costs associated with household.

The top 5 interventions had MSs > 4.17 ≤ 5.00, which indicates that the extent to which these factors reduce the running costs of households can be deemed to be between a near major extent to a major extent / major extent. The last 3 ranked interventions had MSs > 3.33 ≤ 4.17, which indicates that the extent to which these interventions reduce the running costs of households can be deemed between some extent to near major extent / near major extent. This is in alignment with the findings in the literature, especially that of Madungwe & Sakuringwa (2007: 1234) and Manaktola & Jauhari (2007: 363)

Table 4.6: Reducing running costs of households

Intervention	**Frequency (%)**							**MS**	**Rank**
	Un-sure	**Does not**	**Minor ……Major**						
			1	**2**	**3**	**4**	**5**		
Turning off lights when leaving the room or not in use	2.9	0.0	2.9	0.0	8.8	14.7	70.6	4.55	1
Installing a geyser time switch	5.9	0.0	2.9	5.9	0.0	14.7	70.6	4.53	2
Turning off electrical appliances when leaving the room or not in use	2.9	0.0	2.9	0.0	8.8	23.5	61.8	4.45	3

Using LED (energy saving) light bulbs	8.8	2.9	5.9	0.0	5.9	8.8	67.7	4.35	4
Making use of natural lighting during the day	2.9	5.9	5.9	0.0	2.9	11.8	70.6	4.27	5
Using solar power	5.9	8.8	8.8	0.0	5.9	5.9	64.7	3.97	6
Using water tanks to collect rainwater	2.9	8.8	8.8	2.9	0.0	8.8	67.7	3.74	7
Installing grey water systems to recycle water	20.6	11.8	8.8	0.0	8.8	11.8	38.2	3.42	8

DISCUSSION

Sarabia-Sanchez and Rodriguez-Sanchez (2013: 121) found that the internal driving force of households is what motivates people to reduce consumption and that an increase in price will not be the only driving force to which we lesson our consumption. We actually need to tap into the human psyche and create psychological and situational determinants that will drive this behaviour. These findings and that of my own show a direct link in the behavioural statistics associated with reducing consumption and being environmentally conscious.

CONCLUSIONS

Going green for household owners is definitely the future. The findings revealed that most people are aware of the impact that humans have on the environment, and the possible saving on household running costs from going green; however, the respondents tend to lack the motivation to participate in actions such as recycling and the reuse of grey water. This is due to a lack of education concerning the benefits of such actions, as well as the lack of facilities available in South Africa to facilitate the processes involved in recycling and the reuse of grey water. Although, recycling and water saving techniques undertaken by households in South Africa proved to be low; the majority of the respondents in this study indicated that they have adopted most of the energy saving techniques in their household. The aim of this research is ultimately to motivate households to reduce their carbon footprint, to make household owners aware of the costs associated with their actions and that by taking precautionary measures they will not only be benefiting themselves but the environment too.

RECOMMENDATIONS

With regard to green consciousness / environmental awareness; although the majority of the respondents are aware, there is still more room for improvement. It is therefore recommended that educational institutions and other training organisations focus on this issue at school level, providing the youth with a better understanding of sustainability and the importance thereof. The

municipality should be proactive in addressing issues pertaining to green consciousness in households via advertisement and other means of communication to encourage the reduction of household consumption.

Recycling and other garbage reducing measures posed a major problem; individuals need to investigate easy and effective ways to implement these actions in their household. The South African government should address this issue and provide the public with easier methods. A lack of water saving techniques implemented in the respondents' households is problematic. It is recommended that individuals install grey water systems and rainwater tanks in their household. In general, household owners going green will definitely aid in protecting the environment, securing the protection of life for future generations and reduce household running costs. The only way of ensuring this, is by the contribution of individuals to take the necessary steps towards conservation.

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MONITORING AND ANALYTICS TO IMPROVE SERVICE: 'MANTIS'

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Keywords: *Water Monitoring Analytics*, *User interface Global South*

Abstract:

Worldwide, 780 million people live without basic and reliable water supplies. Many rely on hand pumps for their water supply but at any one time a third of pumps are not working. The MANTIS monitoring unit is a self-contained, self- powered remote monitoring device for water hand pumps. With a low-tech design but utilising current Artificial Intelligence techniques, MANTIS records daily pump use patterns and detects irregularities indicating potential problems, such as wear and tear or a receding aquifer, and provides alerts when pumps breakdown. Using the increasingly ubiquitous mobile network, MANTIS communicates daily by SMS with a webhosted user interface, enabling subscribers to view the operational status of remote hand pumps. Users such as government water supply departments and NGOs with responsibility for hand pumps are thereby equipped to quality control maintenance and repair and to plan for more sustainable water resource management. MANTIS provides a context specific tool to manage this essential infrastructure whilst helping users to improve the health and wellbeing of those relying on them for daily water supply. It is adaptable for use in monitoring increasingly used solar pumped water supply. Low budget pilot installations in Sierra Leone and the Gambia have proved the efficacy of the technology, with a pump breakdown being correctly diagnosed via the interface and confirmed by site visits by local project team members. Funding is currently being sought to facilitate a larger demonstration project that will trial MANTIS units on 100 hand pumps and some solar installations in the Gambia. The project team comprises an LBU academic with broad experience of water management in the Global South, the SME Environmental Monitoring Solutions Ltd. and The GLOVE Project NGO in the Gambia, with extensive input from the Gambian Ministry for Water.

INTRODUCTION

Sustainable Development Goal 6 / Access to safe water

It is reported that over 750 million people across the developing world do not have access to safe drinking water (WHO-UNICEF, 2013). Poor access to safe water contributes to high levels of preventable disease and death. The Sustainable Development Goals (SDGs) (UN, 2015) were a range of developmental targets introduced by UN member states in 2015. Sustainable Development Goal 6 (SDG6) – specifically relates to clean water and sanitation – and aims to ensure universal access to safe and affordable drinking water by 2030. The SDGs seek to build upon progress made towards the Millennium Development Goals (MDGs). The MDGs were a previous set of development targets adopted by the UN in 2000. These included target 7.C to "halve, by 2015, the proportion of people without sustainable access to safe drinking water" (UN, 2008). However, many sub-Saharan Africans still lack access to improved water sources. For instance, it has been reported (WHO-UNICEF, 2013) that only 63% of the population in this region has access to improved water.

Broken water pumps

Hand pumps supply water to over 200 million rural African water users, yet many fail prematurely, causing hardship in the communities reliant on them. Many of these hand pumps are abandoned, or provide intermittent/ poor quality services, or are seasonally dependent. The cumulative effect of such rural water supply failures in Africa over the past 20 years has been estimated by the World Bank to represent a lost investment in excess of $1.2 billion (Bonsor *et al., 2015*). These problems are well documented. For example, a previous study reported that between 20% and 65% of hand pumps installed across a range of African countries were broken, or out of use (RWSN, 2010). Whilst, another recent report has claimed that between 30 to 40% of rural water systems are failing prematurely (USAid, 2016). It has been estimated that some 62 million people, across this region, are impacted by broken water infrastructure (Swan *et al*., 2017). These issues threaten the recent advances that have been made as a result of the MDG and SDG targets.

The reasons for pump malfunctions are complex, and have been attributed to a range of factors including: insufficient local financial resources to fund necessary repairs; limited access to spare parts; limited technical capacity within the user community; inappropriate project implementation and/or technology choice; limited post-construction monitoring and support from external agencies (Moriarty *et al*., 2004). In relation to this final point, it has been reported that less than 5% of WASH (Water, Sanitation and Hygiene) projects are visited after installation, and as such broken infrastructure frequently goes undetected or is not addressed by relevant stakeholders (USAid, 2016). Regular post-construction monitoring of remote water projects may help address some of these problems. However, in many instances such traditional monitoring programs require regular site visits to remote locations, which can hence place heavy time and resource demands on supervisory bodies. There is growing interest in the use of mobile phone based technologies as an alternative method of monitoring water projects.

Review of telemetry application for Water Projects in Africa

Telemetric systems are widely used for monitoring remote activities across the globe. Many such monitoring applications use mobile-phone networks to convey data from a remote location to a central data handling hub. The main advantages of telemetry-based monitoring tools typically relate to the comparatively low costs and wide coverage offered by mobile phone networks. The timeliness of this approach corresponds to recent growth in mobile phone network coverage, coupled with the emergence of low cost monitoring equipment. There is growing interest in the use of telemetry tools for monitoring water projects across Africa. This is highlighted by the emergence of an array of new technologies for monitoring water pumps in developing regions, most notably the SWEETSense, SMART pumps and MoMo projects. These systems utilise a range of remote measurement approaches, including the use of accelerometers, pressure transducers or flow sensors. The effectiveness, and operational performance, of many of these systems are currently being assessed through field-trial investigations. An overview of these systems was previously presented by Swan *et al.* (2018).

METHODOLOGY: DEVELOPMENT OF MANTIS SYSTEM

The MANTIS (**M**onitoring & **AN**alytics To **I**mprove **S**ervice) system was developed through collaborations between Leeds Beckett University (LBU) and Environmental Monitoring Solutions Ltd (EMS). The MANTIS system was designed around five key principles (i.e. ***Simplicity, Low-cost***, ***Ease of deployment, Longevity, Minimal data collection)*** which sought to address the opportunities and challenges highlighted in previous publications (Swan *et al*., 2017). The system has the capacity to transmit data about the performance of community hand pumps without the need for a physical site visit. The system has been designed to work on the AfriDev and India MkII hand pump models, which are two of the most widely used tools for abstracting groundwater in rural locations in the Global South. There are two aspects of the MANTIS system; the hardware unit which is installed at the pump and the web based Graphical User Interface (GUI). The system relies on the use of the GSM network to transmit data in SMS messages from a unit fitted discretely to the hand pump. The SMS Gateway passes the messages to a server running an online application which stores and presents the information on the Graphical User Interface (GUI) where data analytics present information about the location, functional status and historical performance (recent; days/weeks, and less recent; months/years) of the hand pump. The data analytics are used to enable visualisation of pump usage patterns, giving early indication of failure and the nature of failure and providing users of the interface with malfunction alerts and decision support regarding pump maintenance and resource planning. The interface shows the exact geographical location of the water point (recorded when the unit is installed on the water point).

Fig 1. Field trials of MANTIS unit in Bumpe Ngao, Sierra Leone

RESULTS

A recent field trial exercise (Swan *et al.*, 2018) comprised the installation of MANTIS units on 23 hand pumps in Sierra Leone and Gambia (Figure 1). Operational data was conveyed from each

of these sites, on both a routine basis and also by exception (i.e. to confirm pump inactivity and potential failure). The authors believe that the following case study from these field trials demonstrates the potential of the MANTIS system. The following dataset (Figure 2) was collected by a MANTIS unit mounted on a hand pump in the Mbankan district of Gambia.

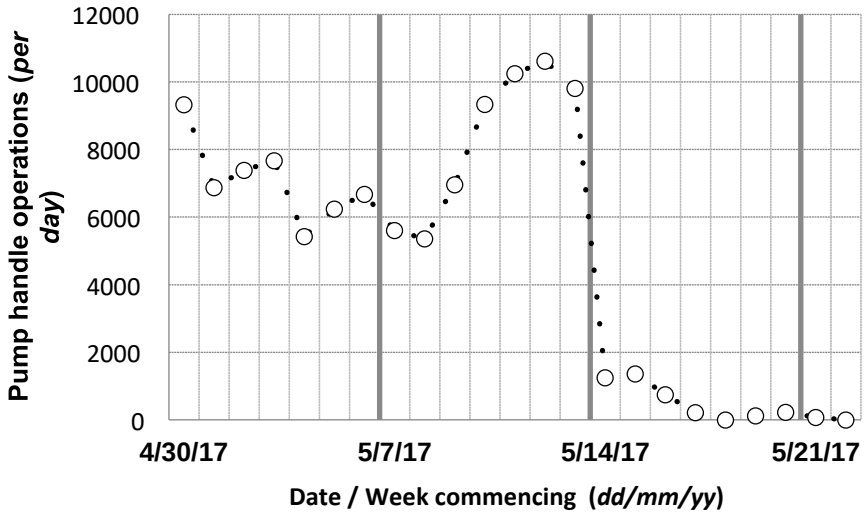

Fig 2. Pump failure event on India MkII hand pump in Mbankan, The Gambia

This data exhibits the usage patterns that were recorded immediately prior to, and after, a pump failure event. Before the 14/05/2017 the pump usage pattern appears to be relatively stable (i.e. between 5000 and 11000 operations per day). After the 14/05/2017, the pump usage rapidly falls to fewer than 2000 uses per day and then gradually drops over the next 5 days to almost zero operations. This 'distinctive usage pattern' was reported to local partners in Gambia, who visited the pump. This site visit confirmed that a pump failure had indeed occurred on 14/05/2017 (i.e. due to a broken pump rod). The subsequent reduction in usage pattern hence reflects that fewer attempts were made to use the pump, and that user attempts continued to fall over the following days as the local community gradually noticed the malfunction and started to use alternative water sources. Indeed by 21/05/2017, nearly all of the local community appear to be aware of the problem as usage attempts virtually ceased. This simple case study demonstrates the principal objective of the MANTIS system (i.e. to remotely detect when monitored water pumps are operational). It is worth highlighting that this outcome was achieved by remotely monitoring and interpreting simple pump usage patterns, with this analysis authenticated by local field based observations.

DISCUSSION

It is envisaged that in future the simplistic data (i.e. pump use trends) collected from individual and neighbouring groups of pumps might be analysed using rule-based algorithms, such as artificial intelligence or fuzzy logic. It is hoped that this approach will be employed to differentiate between different patterns that might indicate pump wear, increasing use, falling water tables or inaction due to a dry water table. However, in order to fully automate the detection of pump failures or, even more significantly, to predict when such failures are due to occur, it will be important to establish when observed usage patterns start to deviate from a pump's normal operational range.

CONCLUSIONS

Many water pumps in remote locations of the Global South are not visited after construction, and as a result broken infrastructure is often not detected or repaired for significant periods of time. This paper has highlighted the emergence of new tools such as MANTIS for monitoring hand pumps. These technologies may lead to an improvement in terms of both monitoring and maintenance strategies, and this in turn could increase the sustainability of water projects. The functionality of the MANTIS system has been successfully demonstrated in the field.

Further trials are planned to thoroughly demonstrate and test a final 'market ready system' within its operational environment. At this stage, it is hoped that the system will be employed by those stakeholders with responsibility for ensuring drinking water provision (e.g. government departments, water operators and NGOs. It is intended that Malfunction alerts will support timely and efficient mobilisation of local pump mechanics thus increasing pump uptime and water availability. MANTIS provides information about: pump use, pump maintenance and water resources. Currently, the only way for organisations to know whether drinking water is being reliably supplied and pumps well maintained post-installation, is to physically visit each village to check the systems. NGOs who have supplied hand pumps can use MANTIS to support maintenance provision in a similar way to the Sweet Sense 'ambulance' model (GSMA, 2016), but with a simpler, and an order of magnitude cheaper technology. MANTIS should also provide reliable historical field data, which should also assist government bodies with: planning for water resources, quality control of installations and maintenance, reporting to funding institutions, and will provide evidence for future funding applications and budgeting strategies.

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USE OF RECYCLED RUBBER TYRES AS AN ALTERNATIVE INGREDIENT IN THE MANUFACTURE OF CEMENTITIOUS BLOCK MATERIALS

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Keywords: Recycled rubber tyre, cementitious block, sustainability, performance.

Abstract

The growing world population and rapid industrialisation have generated vast quantities of solid waste contributing to an energy and environmental degradation crisis. In particular, there are excessive numbers of waste rubber tyre that are a waste management issue. Previous research has shown the introduction of recycled rubber tyre crumb to building material can improve the durability, thermal and acoustic performance in buildings. Large numbers of low-income buildings in South Africa are constructed from cementitious block but perform poorly. The lives of dwellers could thus be greatly improved because of material changes whilst potentially creating a more cost-effective and sustainable building block. The aim of the research was thus to ascertain whether the introduction of recycled rubber tyre crumb can improve the durability, thermal and acoustic performance of cementitious block whilst creating a more sustainable low-cost building material. The objective was to test alternative cementitious building material mixes incorporating recycled rubber tyre crumb to quantify the performance when compared to existing blocks and determine compliance with South African National Standards. The research showed a decrease in compression strength of 75% at 30% rubber replacement. The thermal performance tests showed an opposite result with a 52% lower transfer at 30% rubber replacement. It also found that crumb rubber possesses less bonding ability, which has an effect on the strength of the concrete blocks, negatively impacting on their potential use for low income dwellings. The fire, thermal and acoustic performance tests showed benefits for the occupants. It is recommended that tests on pre-treated crumbed rubber with improved mix control be conducted to determine whether this would enable the use of the blocks for loadbearing structures. A further recommendation is that research be conducted using a standardised block wall to enable a sustainable life cost analysis to be carried out to determine viability for commercial production of blocks.

INTRODUCTION

A growing world population and rapid industrialisation generate vast quantities of solid waste daily that has contributed to an environmental degradation challenge. In particular, there are an excessive numbers of waste rubber tyres with 275 000 tonnes of these becoming waste in the Republic of South Africa (RSA) every year (REDISA, 2012). The scrap tyre is, however, an important solid waste in the RSA, yet the same properties that make tyres desirable in turn make their disposal and recycling a challenge. Tyres do not break down in a natural environment thus creating a need for recycling methods.

Waste tyres fall under the general waste category with old tyres usually re-treaded, reclaimed, de-vulcanised to rubber for re-use or dumped in landfill (Mulaudzi, 2017). This creates an abundance of waste rubber tyres that in turn result in a waste management issue. Waste tyre management encompasses the collection and transportation, storage and pre-processing for delivery of waste tyres as well as the funding of operations aimed at reducing waste tyres in the environment. Approximately 12 million tyres currently sit in landfill (REDISA, 2012) and thus the Recycling and Economic Development Initiative of South Africa (REDISA) plan was developed, a comprehensive and inclusive plan with the potential to address the waste tyre problem. (Nkosi *et al.*, 2013)

Due to the unprecedented rate of urbanisation, human settlement is a major challenge in RSA (Ziblim *et al.*, 2013). In 2004, the RSA government revised its housing policy to include a comprehensive national programme dedicated to the upgrading of informal settlements in the country (cidb, 2011). One of the contributing factors towards such living conditions is the inadequate performance of the selected building materials with which houses were constructed. The current state of affairs and tendency is that the construction of Reconstruction and Development Programme (RDP) houses are unable to meet basic technical requirements that result in the houses becoming uninhabitable because the project product is of a low standard and/or in poor quality condition (Ogunfiditimi, 2008).

The RSA has good energy efficiency legislation in the form of SANS10400-XA (SABS), first enacted in 2011, which specifies energy efficiency requirements for all buildings. Although these requirements are achievable with sufficient funds and expertise available, and are a part of building regulations, they pose a problem to achieve for RDP houses, so these are exempt, partly due to the constrained budgets and materials available for their construction (Dobson, 2015). The main choice of building material for the walls of these structures is single skin concrete block, which generally performs poorly in terms of its thermal, acoustic and water repelling properties.

The use of rubber tyres in construction materials and methods is becoming prevalent and is a way forward to sustainability (Ling *et al*., 2010; Sodupe-Ortega *et al*., 2016). The need to incorporate recycled materials in building products is becoming more important and thus rubber tyres are being adapted for different uses in components such as masonry walls, insulation, roofs and road works due to its favourable characteristics (Kathomi, 2009). This research thus set out to ascertain whether the introduction of recycled rubber tyre crumb could improve the existing performance of cementitious block, creating a more sustainable low-cost building material to improve the lives of low-income dwellers in these buildings across South Africa. The objectives were to test alternative cementitious building material mixes that included recycled rubber tyre crumb, to quantify the strength, thermal and acoustic performance of these compared to existing cementitious building materials and review compliance of these with the energy efficiency requirements of SANS10400-XA.

THE CEMENT BLOCK CHALLENGE

Research conducted by Becker (2010) on concrete blocks observed there was insufficient information relating to the performance of concrete blocks, particularly in warmer climates, such as the Mediterranean region. In warmer countries, thermal mass is more important

than in colder climates, where thermal insulation levels can be much lower, leading to a propensity for masonry construction. Due to the mild winters, conduction heat losses do not justify multi-layered construction, and the prevailing exterior walls are composed of a single layer of hollow-core concrete blocks.

Ling *et al.* (2010) highlighted that recycled waste tyres crushed into particles with different sizes could subsequently be used as aggregate in cement mortar and concrete. In theory, the properties of normal concrete would be affected by the inclusion of waste rubber particles, with Al-Mutairi *et al.* (2010) ascertaining that the workability of concrete decreased gradually with increasing percentage of rubber particles and the density of rubberised concrete decreased gradually with increasing rubber particle percentage because of the low specific gravity of rubber particle. Ozbay *et al.* (2011) confirmed this further observing that the compressive strength and splitting tensile strength reduced, while its toughness and ability to absorb fracture energy enhanced significantly. Yilmaz *et al.* (2009) and Ganesan *et al.* (2013) verified that flexural strength of concrete increased with the increase of crumb rubber percentage. The concrete panels made with rubber particles proved to have better sound and thermal properties than plain concrete (Sukontasukkul, 2009).

During practical applications, the shrinkage of rubberised concrete was usually associated with the size and shape of the rubber particles. Turatsinze *et al.* (2007) reported that the shrinkage increased with the increase of replacement of rubber particles. The unique properties of rubberised concrete have seen it used as an exterior wall material, for rubberised concrete blocks materials and as a trench bedding material (Lv *et al*., 2015). The introduction of rubberised concrete has shown an improvement in thermal and acoustic insulation for small machinery housing structures as well as enhanced thermal insulation for flooring in buildings. Concrete mixed with crumb rubber has better toughness and impact strength than ordinary concrete, and has better heat insulation and sound insulation properties (Ali *et al.*, 2015).

Crumb rubber has, however, a bad interface compatibility with inorganic materials.
Cement paste is a hydrophilic material, while the surface of crumb rubber is hydrophobic. Thus, the adhesion between crumb rubber and cement paste is poor, impairing the mechanical properties of the rubber cement matrix material and limiting the development and application of rubber cement based products. Mohammadi *et al.* (2016) evaluated the performance of rubberised concrete prepared with sodium hydroxide (NaOH) treated rubber and found that this treatment method resulted in a notable improvement in the compressive strength and moderate enhancement in the flexural strength. However, it did not lead to better adhesion characteristics of the rubberised concrete for all treatment methods due to the rougher surfaces of the modified rubber particles (Liang *et al.*, 2016).

In a study conducted by Sukontasukkul (2009), both thermal and sound properties of crumb rubber concrete panels were investigated in terms of thermal conductivity factors, thermal resistance with heat transfer, conductance value, sound absorption at different frequencies and noise reduction. With respect to size, the rate of heat transfer decreases as the crumb rubber decreased. With respect to content, concrete with the large sized crumb rubber gave the highest value of heat transfer rate, and those that have small sized crumb rubber showed smaller values. As for the effect of rubber content, the rate of heat transfer decreased with the increasing rubber content. Comparing the same size, the smallest value is at 30%, and

increased gradually at the rubber content of 20% and 10% respectively (Sukontasukkul, 2009).

The crumb rubber (CR) lightweight concrete appeared to have superior sound absorption properties to that of plain concrete, although the results were inconclusive at the lower frequency range. At the mid-frequency (500 Hz), the CR concrete began to show slightly higher A-values. At frequencies higher than 1000 Hz, the ability to absorb sound in this range for all CR lightweight concrete was much better than that of plain concrete. This indicated that crumb rubber concrete (CRC) is a better sound absorber at the highfrequency range than plain concrete. The sound absorption of CRC was poorer than that of AAC at every frequency. This is due to much lower densities of the AAC that are about 400 - 800 kg/m3 compared with the CRC that are between 1800 - 2100 kg/m3.

RESEARCH REVIEW AND METHODOLOGY

Research Method

To ascertain whether the introduction of recycled rubber tyre crumb can improve the durability, thermal and acoustic performance of cementitious blocks, the researchers conducted an experimental quantitative design method to determine the performance when compared to existing cementitious building materials. The primary data obtained was from the manufacturing and testing of the rubber cementitious blocks in the Nelson Mandela University Concrete and Soil Laboratory as well as Fire Tests at the Aberdare Cables testing facility. The manufacturing and testing of the rubber concrete blocks determined the effect of the replacement of aggregate with crumbed rubber. Tests conducted determined if the independent variable(s) (controlled) cause an effect on the dependent variable (the variable measured for change). The experimental outcomes evaluated were to establish the result within a credible range or standard.
The materials used in the study were:

- Builders river sand;
- Ordinary Portland cement;
- Recycled crumbed rubber, and
- Stone, aggregate and water.

100mm x 100mm standard cubes replaced concrete blocks (dependant variable) for the tests due to a failure to manufacture rubber concrete blocks (see research results). The concrete strength was set at 25MPa whilst crumbed rubber weight determined the replacement quantity for the aggregate. REDISA supplied crumbed rubber (independent variable) at a chosen particle size (0.250mm). This was on given percentages of 10 %, 20 % and 30 % of the aggregate, based on previous research that showed a significant decrease in compressive strength where over 30 % rubber replacement values exist. The cube tests used a mix design based on a grading analysis, loose and compacted bulk densities, as well as the relative densities of the materials. The mix design provides the amount of material needed per cube test.
The researchers conducted the following tests on the cubes:

- Strength test (compression);
- Fire Performance;
- Thermal Performance, and
- Acoustic Performance

Research results Large scale manufacturing test

The researchers attempted to manufacture rubber concrete blocks at a commercial establishment, Zikhona Bricks in Port Elizabeth, RSA. Manufacturing testing used concrete block size 390x190x190 and the raw materials used included:

- 25kg 10 mesh crumbed rubber;
- 25kg 20 mesh crumbed rubber;
- 25kg 40 mesh crumbed rubber;
- 25kg 60 mesh crumbed rubber; and
- Lafarge sand and cement.

The particle size ranged from 0.25mm to 2.00mm. The untreated crumbed rubber was thoroughly premixed in a container, by hand, to ensure an even particle distribution.

The first manufacturing test involved a 10% crumbed rubber replacement of the sand aggregate. The aggregate was weighed to 93kg and 7kg of crumbed rubber was added to this. These materials were then combined with 6kg of cement and poured into the block mould. The block could not hold its shape and fell apart. It was evident that the crumbed rubber had not bonded to the cement. Along with this initial analysis, other concerns were that the mix was not large enough i.e. the raw materials did not mix properly in the mixer.

The second test involved a 15 % crumbed rubber replacement of the sand aggregate. The raw materials increased to 340kg of sand aggregate and 60kg of crumbed rubber. The same process followed with 24kg of cement added. Once again, the blocks did not hold their shape with the analysis suggesting the crumb rubber did not bond with the cement. The following factors were determined:

1) The crumbed rubber had not bonded with the cement;
2) The mixing process of all the materials could not be assessed, creating the possibility that the materials were not mixing;
3) The scale weighed out material in 5kg increments, and 4) The mixture did not have time to set in the mould.

In order to eliminate these factors to produce a viable test block, the raw material quantities were reduced and the process moved into a controlled laboratory environment.

Mix design

The Cement and Concrete Institute (C&CI) method, based on ACI Standard 211.1-91 was chosen. Some minor modifications were made to accommodate for the rubber, as this test is premised on an optimum amount of stone in the mix linked to stone size, stone packing capacity and the fineness modulus of the sand, as well as the volume of concrete being the sum of the volume of water plus the solid volumes of cement, sand and stone (Owens, 2013). A grading analysis was conducted to assess the particle size distribution of the materials.

After a process whereby the sand was raked out and dried, both in an oven and on an open tray for 2 days, the sand, along with other fine aggregates, were then passed through a series of sieves to determine the grading. These were blended with the aggregates and compared to a specification mean to show if the blended aggregates were compatible. Loose and compacted bulk densities were then calculated for the aggregates. The relative density of three materials: builders' sand, stone and grit, were then tested. The relative density of materials is an important factor as it provides information required to aid in the cement/water ratio for concrete mixing. All materials were weighed out individually. The sand and grit were mixed together through a dispenser until material was uniformly mixed (three times). The same process was followed with the rubber added to the sand and grit. The replacement of rubber was from the overall weight of the fine aggregate, with R1 – 10%, R2 – 20 % and R3 – 30 % the replacement values. Table 1 provides a breakdown of the weight of material per mix. Cement, water and stone are a constant throughout with the adjustment for the inclusion of rubber made with the fine aggregates at the 71:29 ratio derived via the C&CI method.

Table 1: Weight of materials for mix

MIX	MATERIAL (kg)					
	Cement	Water	Stone	Sand	Grit	Rubber
Control	3.26	2.25	9.79	1.51	3.53	0.00
R1	3.26	2.25	9.79	1.36	3.18	0.71
R2	3.26	2.25	9.79	1.21	2.82	1.01
R3	3.26	2.25	9.79	1.06	2.48	1.51

Compressive Strength

The compressive strength test indicates the cubes resistance to breaking under compression forces. A Kingtest Auto 2000 Compression Testing Machine was used to test three samples of each Control, R1, R2 and R3 sample cube. Figure 1 shows the compressive strength test results. Three samples were tested and the average compressive strength for each was:

- Control – 348.8 kN;
- R1 – 281.7 kN;
- R2 – 157.0 kN; and • R3 – 88.5 kN.

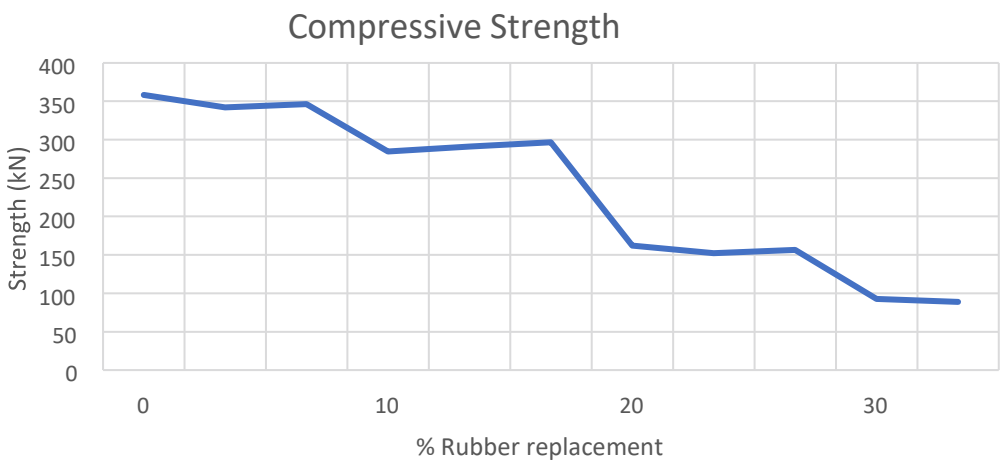

Figure 1: Compressive strength test results Fire Performance

Two fire performance tests, namely a flame resistance test and a smoke density test, took place at Aberdare Cables fire testing facility in Port Elizabeth, South Africa.

Smoke Density

The smoke density test was conducted under international standard IEC 61034-1 (2005). The standard fire source shall be 1,00 l ± 0,01 l of alcohol having the following composition by volume: ethanol: 90 % ± 1 % methanol: 4 % ± 1 % water: 6 % ± 1 %. To ensure uniform distribution of the smoke, a table-type fan shall be placed on the floor. The fan axis being between 200 mm and 300 mm from the floor and the distance from the wall being 500 mm ± 50 mm. The fan shall have a blade sweep of 300 mm ± 60 mm and a flow rate of 7 m3/min to 15 m3/min. The test sample shall remain in situ during the test so the cubes were held up by two metal rods. The test is considered as ended when there is no decrease in light transmittance for 5 minutes after the fire source has extinguished or when the test duration reaches 40 minutes. The test chamber temperature (°C) was taken at the start of the test as well as the Lux value of the room when dark and fully lit. The Lux value of the fully lit room was taken after two minutes allowing for the light to stabilise. The minimum light intensity (lux) was then to be recorded at 1 min intervals for the test duration. According to standard IEC 61034-1 (2005), the test is a failure if the result is lower than 60 %.

Figure 2 shows the results for the smoke density tests. Each test ended at 35 min as the flammable liquid extinguished. The lux value remained stable for 5 min.
The minimum light transmittance for the Control was 70.8 lux. Min. light transmittance = [1-(72.65-70.8/72.65-6.7)] x100% = 97.19 %
The minimum light transmittance for R1 was 65.6 lux.
Min. light transmittance = [1-(70.6-65.6/70.6-6.7)] x100% = 92.18 %
The minimum light transmittance for R2 was 65.6 lux.
Min. light transmittance = [1-(77.6-65.6/77.6-6.7)] x 100% = 83.07 %
The minimum light transmittance for R3 was 60.64 lux.

Min. light transmittance = [1-(72.66-60.64/72.66-6.7)] x 100% = 81.85 %

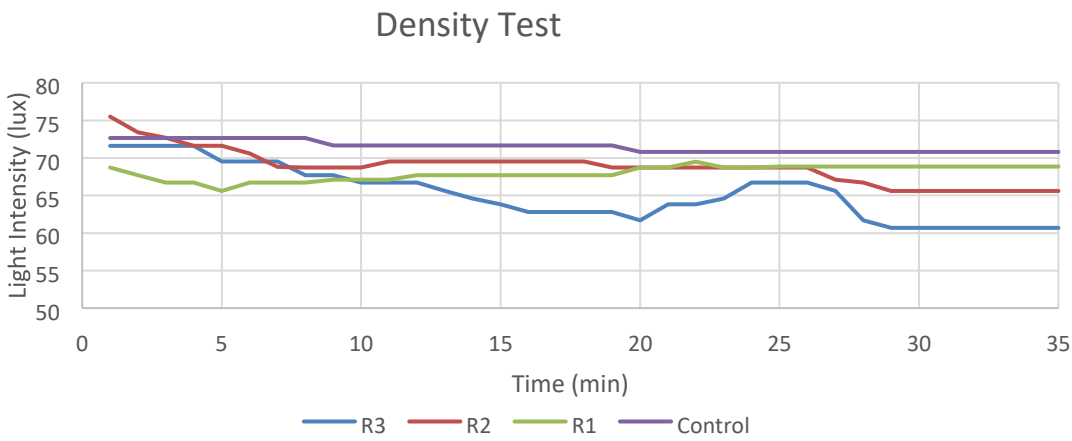

Figure 2: Smoke density test results Fire and Thermal Performance (Flame resistance)

The flame resistance test conducted used the following equipment:

- Bunsen burner;
- Major Tech MT630 Thermometer;
- Thermal couples, and
- Rubber and concrete cube.

The flame of the Bunsen burner was calibrated using IEC 60695-11-2 standard (2003). For measuring the temperature of the block, a class 1 mineral-insulated, metal-sheathed finewire thermocouple with an insulated junction is used, the sheath resistant to continuous operation at a temperature of at least 1050°C. Once calibrated, the propane and compressed air flame was applied to the centre of the block for 15 min. The thermometer, attached with thermal couples placed on the opposite side of the block, took the temperature every 5 min.

One cube sample from each rubber percentage replacement was tested. Figure 3 shows the results of the flame resistance tests. A linear extrapolation for each cube test was produced to show the temperature at 60 minutes. The control (C1) temperature at 15 minutes was 32 °C with an extrapolated 65°C temperature at 60 minutes. R1 temperature at 15 minutes was 29 °C with a 48 °C temperature at 60 minutes. R2 temperature at 15 minutes was 27 °C with a 40 °C temperature at 60 minutes. R3 temperature at 15 minutes was 25 °C with a 31 °C temperature at 60 minutes.

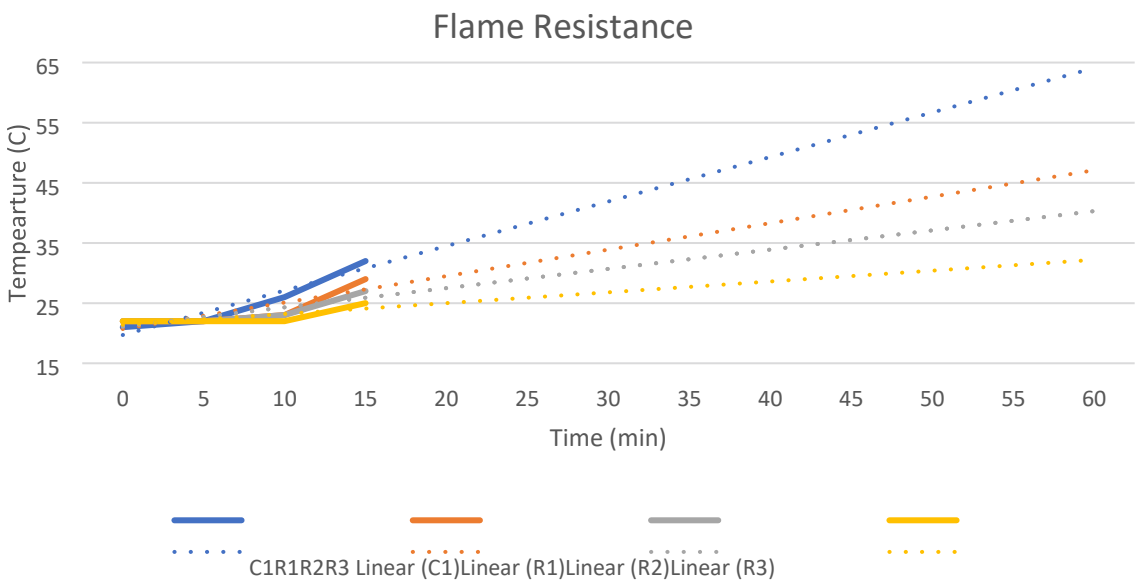

Figure 3: Flame resistance test results Acoustic Performance

The comparative testing method for acoustics is essentially a 'knock' test. The test involves a controlled 'knock' on one side of the block with the sound vibrations measured on the opposite side of the block. Several 'knocks' are conducted per sample with an average being taken from each sample and then compared. Figure 4 shows the results for the acoustic performance presented in the form of line graphs with an average reading for each test. The average reading for Knock Test (C) was 207.58. For Knock Test (R1) it was 197.93, for Knock Test (R2) was 194.11 and 179.69 for Knock Test (R3). The highest reading for C, R1 and R2 was 1023 and for R3 was 773. The lowest reading for C, R1, R2 and R3 was 50. R1 average was 5.65 % lower than C. R2 average was 6.5 % lower than C. R3 average was 13.5% lower than C.

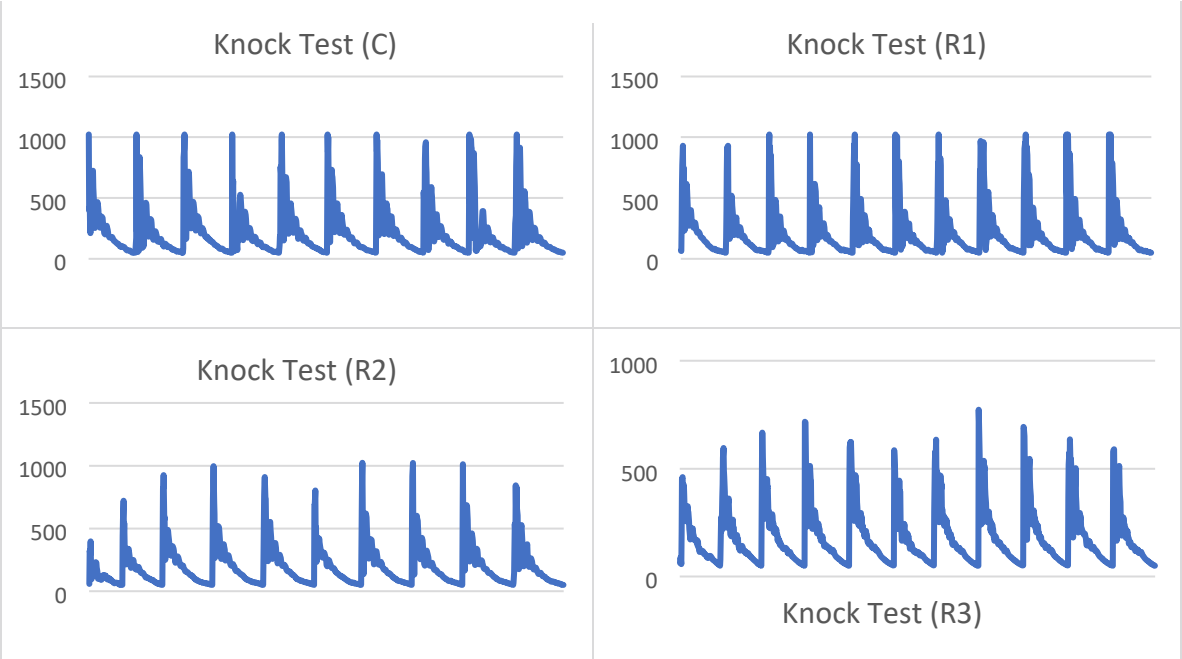

Figure 4: Acoustic performance line graphs

DISCUSSION

Compressive strength

The results from this study showed a significant decrease in compressive strength with an increase in rubber percentage replacement. The compressive strength of R1 was 20 % less than that of the control, R2 55 % less and R3 75 % less. Issa and Salem (2013) compressive strength tests showed a reduction in compressive strength of 12 % at 15 % rubber replacement and 44 % reduction at 25 % replacement. To improve the bonding between cement and crumbed rubber particles pre-treatment of the rubber using a NaOH solution increases the concrete compressive strength by 6% and 15% at seven and 28 days, respectively, compared with non-treated rubber concrete and hence this is a feasible way to overcome some of the loss of compressive strength (Youssf *et al.*, 2014). The adhesive strength between crumb rubber and cement improved by 5.1 %, 17.9 % and 41.1 % respectively due to NaOH treatment, oxidation and sulphonation modification. Lv et al., (2015) stated that the increase in rubber particles from 0 to 100 % resulted in a gradual decrease in compressive strength from 41.5 MPa to 7.8 MPa which is equivalent to an 83 % reduction in compressive strength.

Fire and thermal performance

The research did show that the use of crumbed rubber tyres in cementitious materials is fire resistant. All rubber replacement samples and the control performed adequately in the flame resistance test. The smoke density test showed that the rubber replacement samples did not release a quantity of smoke deemed dangerous. For noting, this fire resistance test was not a true representation of a fire, therefore categorising this as a fire test is inaccurate. The method was more flame resistance with a controlled flame on a singular point at a controlled temperature. However, a study on fire performance using high strength concrete incorporating recycled rubber by Olivares and Barluenga (2004) indicated performance changes due to channels being left open when the rubber particles burn, allowing the water vapours to escape, thus reducing stress due to vapour pressure.

Results from a study conducted by Benazzouk *et al.* (2008) indicate a clear reduction in thermal conductivity of the composite material with the addition of rubber particles. This is due to the entrapped air within the mixture increasing the air content of the block thus providing resistance to thermal transfer through the block. The flame test provided an indication towards the thermal performance of the cubes. The test for thermal resistance showed an improvement in thermal performance when compared to the control sample. This study achieved a 24 % lower temperature for 10 % rubber replacement compared to the control, 39 % lower temperature at 20 % rubber replacement and 52 % lower temperature at 30 % rubber replacement. This leads us to suggest that with an increase in rubber content, rubber concrete blocks will have better thermal performance. The smaller thermal conductivity meant the stronger capacity of thermal insulation of material with certain thickness (Zhu & Yu, 2016).

Ocholi *et al.* (2014) showed heat capacity of concrete with 5% rubber particles content increased slightly by 1.24% before a steady decline to 29.7% with higher percentage (up to 25%) of rubber content. This indicates a slight increase in heat storage capacity, followed by significant decline, which is likely to have an adverse effect on thermal mass.

Acoustic Performance

The use of crumbed rubber tyres in cementitious materials improves acoustic transmission performance characteristics. When compared to the control sample, the values were 6 % lower at 10% rubber replacement, 4% lower at 20% replacement and 13.5 % lower at 30% replacement. Mohammed *et al*. (2012) stated crumbed rubber blocks have better sound absorption compared to conventional concrete blocks.

CONCLUSION

The use of crumbed rubber tyres in cementitious building materials decreases the compressive strength. The use of crumbed rubber concrete blocks should therefore not be included in the primary structure of buildings due to this low compressive strength. The crumbed rubber concrete blocks can be utilised for secondary structures i.e. non-loading bearing walls. These materials could be especially profitable in the building of auditoriums and highway sound barriers (Fraile-Garcia *et al.*, 2016) due to the improvement in acoustic transmission requirements. The C&CI method produced shortfalls regarding the quantity of mix required with an improvement in the mix design required in order to overcome the strength challenges. This can be achieved by testing varying particle sizes to determine the strongest bond between cement and rubber particles. Further analysis is required to determine the optimal particle size of the rubber and to conduct grading analysis of the crumbed rubber mixed together with the aggregates.

Pre-treatment of the rubber to improve the bond with cement particles will enable testing and potential commercial manufacture to a standardised block size. Tests for strength, thermal, fire and acoustic performance conducted by a testing bureau on a fully constructed 2.7m x 2.7m wall would determine if the addition of crumbed rubber tyres in concrete blocks were cost-effective. A life cost analysis needs to be conducted on the materials used for that test to determine sustainability of the process. The life cycle cost of an ordinary concrete block will determine the additional cost of having to manage excess waste rubber tyres and the environmental impact thereof.

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DEVELOPING AND TESTING A BPE APPROACH FOR GREEN BUILDINGS IN INDIA

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Keywords: building performance evaluation, India, green buildings

Abstract

The Indian Green Building Council claims that India is the second country in the world with the largest registered green building footprint; however, independent evaluation of post-occupancy building performance of such buildings is rare in India. This paper seeks to develop, test and refine a building performance evaluation (BPE) approach for the Indian context (I-BPE), to empirically measure and provide suggestions to improve the actual energy and environmental performance of green buildings using low-cost sensors, occupancy surveys, discussions with design teams, review of design documents, and analysis. Firstly, a critical review of BPE-related studies of Indian buildings is conducted to identify the study elements, methods and tools that are commonly used for performance evaluation in India. These methods are then compared with those used in the UK, for assessing and disaggregating energy use, monitoring environmental conditions and understanding of occupant satisfaction, to customise them for the Indian context in terms of data accessibility, relevance, user expertise and costs. Lessons from the UK's experience through Innovate UK's BPE programme are augmented with Indian building industry experience. The resultant customised I-BPE approach is first tested on a pilot, and followed by a whole building performance evaluation of a green building during the inuse stage. This BPE case study is used to refine the appropriateness for the I-BPE approach for the Indian context, and provide insights for improving future building design, engineering and management. The intent of this integrated and customised approach for assessing real building performance in India is expected to assist the building industry in the delivery of better performing buildings. It will also improve pedagogy across schools of engineering and architecture with better understanding of actual performance.

INTRODUCTION

India is considered an important focus for mitigating energy consumption in buildings due to rapid growth and urbanization [1]. Green building certification councils have seen this as an opportunity; the Indian Green Building Council (IGBC) claims that India is the second country in the world with the largest registered green building footprint (with over 5.29 billion square feet), and over 4,553 projects registered for green building rating (as of April 2018) [2]. However the green building movement in India like most countries is lacking an important link: ensuring that the design intent of such buildings is realized. Research, continually demonstrates that green building rating and certification systems do not always deliver the expected energy performance [3], occupant satisfaction [4] or indoor environmental quality (IEQ).

Recently in the UK, the energy performance was found to be two to nine times higher than the "as-designed" models in 29 high performance non-domestic buildings from the Building Performance Evaluation (BPE) programme funded by the UK Government's innovation agency, Technology Strategy Board (now Innovate UK) from 2010 to 2014 [5]. In the USA, one study comparing the energy model predictions with actual energy performance of a LEED certified university building, found the building consuming twice the predicted energy usage while causing a high level of occupant dissatisfaction [6]. In Bangalore, Sabapathy et al. [7], found a large range of energy savings for LEED-certified information technology facilities and no clear incremental increase in energy efficiency, where, for example, the LEED Silver and Gold facilities performed better than one of the LEED Platinum facilities.

It is hypothesized that due to its lack of rigorous construction documentation and commissioning processes, the performance gap in India is at least as prevalent as it is in other countries. Verifying the performance of buildings built to sustainability standards in India will assist in closing the information loop between design and operation towards faster realization of the potential of green and high performing buildings. As yet, post-occupancy studies in India are limited to individual components or systems, and no studies on whole building BPE that establish the gap between design intent and actual performance. Notably, Green Rating for Integrated Habitat Assessment (GRIHA) version 2015 includes a performance assessment requirement which reviews whether energy systems, water systems and solid waste management systems of the building are performing as predicted and match the information provided at the time of award of provisional GRIHA rating. The Green Building Certification Institute (GBCI) launched the ARC system for LEED as well as non LEED buildings to measure performance, make improvements and benchmark against other projects. This is a start for verification of design intent but can be limited especially when not mandatory.

Also most studies that look at the performance gap compare (uncalibrated) design stage models with actual building performance, rather than using the model inputs to focus on the causes that may lead to sub-optimal performance. Simulation models at the design stage are made with certain assumptions since all information about the building and its operation is not available during the design stage. These models are meant for comparative analysis or compliance with codes and standards, and include operational inputs that are best guesses at the time of design, or mandated by the enforcement authorities. Hence they cannot be directly compared with the inuse building performance without some level of calibration with real data.

Within the context of encouraging BPE for (at least) all newly built certified green buildings in India, this paper outlines the process of developing a BPE approach for the Indian context (I-BPE).
The present study is part of the Learn-BPE project[1] which is developing a robust methodology for India, that not only establishes the performance gap using appropriate comparisons, but also makes the findings more actionable as feedback to the design and operations teams.

[1] This study is part of a Newton Fund UK-India research project on learning BPE for improved design and engineering in India (Learn-BPE).

1. Firstly, a critical review of BPE studies in India is conducted to identify common study elements, methods and tools used for performance evaluation in India.
2. These methods are then compared with those used in the UK, for assessing and disaggregating energy use, monitoring environmental conditions and understanding of occupant satisfaction, to customise them for the Indian context in terms of data accessibility, relevance, user expertise and costs.
3. A I-BPE approach for the Indian context is formulated and tested on a pilot building and a green case study building during the in-use stage, to refine its appropriateness for the Indian context, and provide insights for improving future design, engineering and management.

RESEARCH METHOD

Figure 1 shows a summary of the methodology of the I-BPE development process. Following a critical review of BPE studies of Indian buildings to identify common study elements and tools (1a), these are then compared with BPE methods commonly used in UK literature (previous section). Next, BPE methods are categorized and outlined based on the Innovate UK's BPE programme and prioritized for customization in the Indian context in terms of data/tool accessibility, relevance, user expertise and costs (1b). The result, a customised I-BPE approach (1c), was then critically reviewed from the Indian experience perspective considering climatic, design and construction, maintenance and management differences in contrast to the UK. Following this, the methods were trialled on a pilot study building to understand the data collection procedure for various parts of the methodology, challenges, and gaps in the customized methodology (1d). This helped to refine the methodology for the case study building, devise a better monitoring plan and carry out on-site measurements. Finally, the I-BPE methodology was tested on a green building case study during the post-occupancy stage, in the winter season for 14 days (6th- 20th February 2018), to refine the method for appropriateness in the Indian context, and provide insights for improving future building design, engineering and management (2-4). The detailed I-BPE methods are outlined in the following section as the reader is walked through the development process.

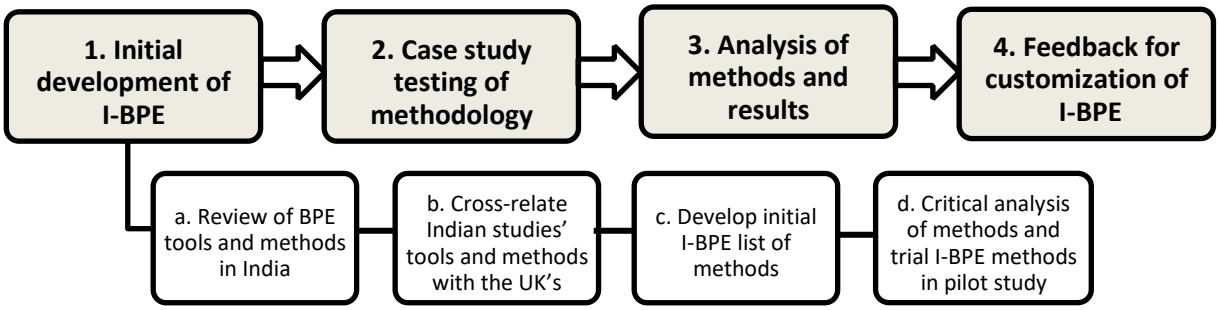

Figure 1. Methodology flow chart

Criteria for selecting pilot study and (full-scale) case study buildings

The pilot building was selected for proximity and accessibility. At this stage green building certification was not necessary to perform a pilot test of some BPE methods. A new University

library building in Ahmedabad, occupied since July 2017, was selected for the pilot study. Figure 2 (left) shows the exterior view of the library building. In contrast, a guiding factor for the full-scale case study building (figure 2, right) selection was that it had to have documented energy performance targets so that this could be evaluated against measured parameters from the I-BPE trial, to identify any performance gaps. The building is certified LEED Platinum and GRIHA-5 star rated. Second, due to the short length of the trial, the building must be occupied for at least one year so that there is at least one year of energy data (accessible) and the building users are well acquainted with the building functioning and various systems. Based on these criteria, an academic building in a University in Jaipur was selected.

Figure 2. Pilot building (left), case study building (right)

LEARNING FROM UK EXPERIENCE

For the purposes of itemizing methodologies for customization of BPE, this study builds onto Innovate UK's (Technology Strategy Board (TSB) at the time) areas of investigation as defined in their BPE guidance document [8]. In so doing this study works from the concept that there are essentially three stages throughout which a BPE can be implemented. These are: (1) As-built evaluation, (2) Initial occupancy stage, and (3) In-use stage.

Tables 2-4 list a review of BPE tools/techniques. For each, a level is added, from 1-3, which considers relevance, a range of necessity, and expertise required. That is:

- *Level 1* should be considered relevant in all cases, highly flexible, highly important to the success of a BPE and or requires little expertise.
- *Level 2* is mid-range between 1 and 3.
- *Level 3* should be considered restrictive to timing, "nice to have" but not essential to a successful BPE and or requires a high level of expertise.

As an example of the level, note that both drawings review and design team interview are considered level 1. This is because it is relatively *simple* to perform and can be considered *essential* or highly important to understanding the building. It is also *flexible* in that it can be

performed at any time in the life of a building (but should be performed at the beginning of the BPE process when possible).

To get an idea of the costs, the average cost of typical BPE methods are extracted from the Innovate UK BPE programme. Cost figures are treated with caution since they are estimates based on applications submitted for BPE competition in the UK and thus they do not represent actual costs incurred. Despite this limitation, they do provide a good idea of the typical costs involved in undertaking different BPE study elements. The cost estimate for each BPE element is based on the following ranges £1,000 – £5,000 = *low cost*, £5,000 - £10,000 = *moderate cost*, £10,000 – £15,000+ = *high cost*.

As-built evaluation stage: The as-built evaluation stage (table 2) primarily covers building diagnostics; to review design, evaluate installation, commissioning compliance and performance of fabric and systems after completion of the building typically before occupancy.

Table 2, Common BPE tools and techniques summary table: as-built evaluation

Tool/ technique	Level	Indian case study tested
Review drawings: compare 'as designed' & 'as built'	1: essential and simple; low cost	Collected drawings and documents from architect and consultants, including LEED and GRIHA rating documents.
Design team interview	1: essential and simple; low cost	Not implemented
Thermal imaging	2: highly flexible but specialist; low cost if not purchasing equipment	Interior and exterior thermal imaging Tool: FLIR TG165
Air permeability test	3: inflexible, specialist; low cost	Not implemented
U-value test	3: semi-flexible, semi-specialist, non-essential; low cost	Not implemented
System commissioning installation review	2: highly flexible but specialist; low to moderate cost depending on methods of system testing required	Reviewed installation and operation of HVAC **and** system, lighting, ventilation and photovoltaic (PV) system: (e.g. PV installed capacity checked and against design target. Sub-metering of actual generation data analysed. Tool: camera
Survey of controls and user-interfaces	1: highly flexible and simple; low cost	Implemented - Tool: camera, usability survey checklist [9]

Initial occupancy stage: The initial occupancy stage (table 3) is almost entirely focused on the occupant's initial experience. Occupant behaviour and their interaction with their buildings, its services and appliances have a significant effect on energy consumption of buildings.

Table 3, Common BPE tools and techniques summary table: Initial occupancy stage

Tool/ technique	Level	Indian case study tested
Handover process observation	2: restricted to specific stages, simple; low cost	Not applicable
Walkthrough survey and interviews	1: flexible and simple; low cost	Walkthrough and interview with facilities management team. Multiple walkthroughs carried out each to assess: installation (photographic or video of systems and use, building design and use of building.

documentation)		Tools: questionnaire, video camera, camera
Occupant questionnaire	1: flexible and simple; low cost	174 responses (78% response rate) Tool: BUS questionnaire, consent forms

In-use stage: The final and potentially longest in duration stage is in-use. This stage is used to collect monitoring data for analysis of building performance. At least one full year is recommended as it provides a full assessment of seasonal variation.

Table 4, Common BPE tools and techniques: In-use stage

Tool/ action	Level	Indian case study tested
Monitoring and submetering of energy	2: varying levels of complexity; some level of data collection and analysis is essential; high cost	Energy use of the building was evaluated based on utility fuel invoice and meter readings. Data from sub-meters of buildings in MUJ obtained from facilities manager
Environmental monitoring and climatic data collection (weather station)	2: varying levels of complexity; some level of data collection and analysis is essential; high cost	Temperature and RH sensors were placed in used spaces on ground, first and third floors in all orientations for a period of two weeks. (first and second floors identical). Tools: HOBO U12-012 data loggers, Tiny tag CO_2 logger / Logging frequency: 5 minutes
Environmental spotchecks	1: simple to perform, provides some essential data; low cost unless purchasing specialty equipment for first time use	Instantaneous globe temperature, RH, illuminance, air quality, temperature, and sound levels were measured. Tools: Testo 540 lux meter, Fluke 922 air flow meter, Testo 540, Extech heat stress meter, and android app for sound meter.
Occupant activity monitoring	2: relatively simple to perform but non-essential; low cost	Not implemented
Occupant comfort / activity diary	2: relatively simple to perform and important for thermal comfort studies, can be difficult as it is dependent on occupant self-driven participation; low cost	Not implemented
Benchmarking and reporting	1: Requires some analytical expertise but is essential to the conclusion of findings for BPE studies; moderate cost	Implemented as PhD thesis; results to be published

Based on the above considerations, this paper sets forth a comprehensive yet simplified I-BPE process. The I-BPE, five essential or 'need-to-know', elements are listed in table 5. Note that where levels are listed they refer to an additive, graduated approach of increased complexity, i.e. level 1 is the basic method to implementing the BPE element and higher levels are to be added to the preceding levels where possible or as the practice advances.

Table 5, I-BPE

No.	BPE elements	Methods

1	Review of design intent	- Collection of all available design documents - Walkthrough / interviews with key stakeholders (e.g. designer, owner, developer)
2	Technical building survey	- Inspection of fabric to whatever extent possible, e.g. including photographic and thermographic survey - Inspection of systems - performed as walkthrough with (or without) knowledgeable guide (e.g. facility/building manager, owner, designer, commissioning agent) - Controls review
3	Energy (consumption and generation) assessment	- Level 1: Systematic meter readings / Energy bill collection / plug load estimations - Level 2: Energy meter monitoring - Level 3: Sub-meter monitoring - Level 4: Large/select plug load monitoring
4	Environmental conditions	- Level 1: Temperature and RH spot readings (coincide with seasonal thermal comfort questionnaire) (internal and external) - Level 2: Temperature and RH loggers/monitoring (internal and external (or weather station data download)) - Level 3: Additional parameters spot read/logged, e.g. CO2, lux, dB, wind speed, VOCs (depending on objectives)
5	Occupant survey	- Level 1: General occupant questionnaire (satisfaction, perception of control, etc.) / Seasonal thermal comfort questionnaires - Level 2: Occupant thermal comfort diary - Level 3: Focus group with occupants to discuss common questionnaire findings

APPLICATION OF I-BPE TO THE CASE STUDY BUILDING

An initial review of the I-BPE process for the case study buildings, the following observations were made. Due to the occupied status of the case study building and length of study, U-value testing was considered too difficult and disruptive to carry out. Also, due to the occupied status of the case study building, the handover process was not observed. Building specific questionnaires were developed to make them more relevant to the climate. Finally, the rating systems' suggested baseline values for the energy performance of the building were used for evaluation.

Following the pilot study, it became clear that access to the building and prior permissions are essential for installing the sensors for monitoring. Success also depends on ensuring access to resources such as drawings and specifications prior to the start of a study and a backup plan for monitoring should be in place if the layout/ access to resources changes on site. To effectively cover all elements, multiple walkthroughs were required with Facility Manager to understand the entire building and all systems. Convincing occupants to complete surveys can be required a brief introduction of the survey, along with a pilot run for survey and analysis to validate the questionnaire itself.

The performance goals of the building were divided in asset (building geometry and building system performance) and operational (schedules, set points, mode of operation such as mixed mode). The design intent is typically focused towards asset (were the required number of

operable windows installed) and may not be directly responsible for operation (are the users operating the windows appropriately). Similarly, another example can be: is the HVAC system capable of providing optimum thermal comfort (asset), whereas, what are the current system set points (operation).

The field study was carried out for 14 days which included measurements, data monitoring, walkthroughs and surveys. The energy performance index for the case study building was measured at 26.5 kWh/m^2/year. For the monitored year (2017), the annual solar generation was 3% higher than the requirement of LEED Platinum rating (7.5%), likely providing a buffer for future efficiency loss. The monitored spaces were thermally comfortable according to NBC 2005 for the monitored period. Most spaces had acceptable noise levels except for open office spaces and classrooms on the second and third floor. Average illuminance levels according to NBC 2005 were met and 82% of occupants felt satisfied with the overall lighting. According to the survey carried out for user control interfaces, all space types had ease of access to controls. Fan and lighting control in all spaces were well designed; however, certain spaces (classroom, personal cabin, and open office) did not have access to thermostat control. This caused discomfort to some occupants. About 79% of occupants from the surveyed population felt that the design met their needs, although improved comfort control would help the building perform better. It was realised that the continuous involvement of the FM team in managing the building has helped maintain acceptable building performance.

DISCUSSION

The following section outlines I-BPE study elements that were found to be helpful, elements that should be emphasised, and where I-BPE may need to be improved as a result of the case study evaluation. Regarding preparation for a BPE study, more time should be spent on analysing the design and rating system documentation to understand the building context properly which would also help in designing a robust monitoring plan. BPE plans should be customized according to the green building rating system being assessed. For example, on-grid illuminance measurements for typical space type might be required, since some rating systems have targets for achieving average illuminance levels. In addition to typical spot measurements, CO_2 decay can be carried out for all typical spaces to measure the ventilation rates in the building. This should be included since some rating systems refer to codes and standards in India that require minimum ventilation rates. Monitoring and spot-measurement equipment should be verified for their specification (accuracy, precision, measurement interval and measurement range).

For a smoother operation, it is advisable to create a daily activity schedule which can be shared and discussed with the facility manager. This will help them to arrange appropriate personnel to accompany and arrange access to all the required areas and building systems. Another crucial step is in preparing a monitoring plan prior to the site visit which can be improved or altered if needed. A one to one interview with the facilities manager is crucial to understand the building, its systems and usage. Documentation of minute details in the form of notes or

photographs and videography should be taken on site. This can help the researcher go back to these notes while analysing the data.

Imported questionnaires (e.g. BUS) require modification for climate and cultural considerations. For more robust analysis, questionnaires can be edited and re-written to be more project/rating system specific prior to the site visit. Occupant focus group interview might not always be possible on-site, especially for office spaces. Researchers will have to encourage people to interact and talk about the building and its facilities. To improve the performance of the building, feedback from a BPE study should be provided to the designers, the management team on how the building can perform better and also to occupants on how to use the building controls in an efficient way.

CONCLUSION

The present study has described the development and testing of the I-BPE framework required for performance evaluation for buildings in India. The field study was extensive in nature and can be replicated to evaluate green rated institutional buildings in India. The building studied was evaluated based on the performance goals (assets and operation evaluation). The study was able to evaluate the building for its asset related performance goals. However, due to gaps in data, the operation evaluation cannot be concluded for this building (e.g. requirement of calibrated models for energy savings comparisons). Learnings from the study will help in carrying out better BPE for future case studies.

The next step involves testing the I-BPE approach on a number of case studies implemented by students using a programme developed for this purpose. The BPE case studies will not only demonstrate the actual performance of the buildings but also the effectiveness and relevance of the methods used and the effectiveness of the developed course to communicate the BPE concepts and methods. The BPE case studies are intended to build trust in the industry, which is currently shy of exposing themselves to liability risk resulting from actual building performance. By demonstrating a positive impact of the case study findings, both in terms of finding ways to improve performance and benefit owners where the actual performance falls short of expectation, and in terms of recognizing commissioning and operation practices that allow building performance to exceed design expectations, the project will encourage a future strengthening of the relationship between the industry professionals and researchers in academia.

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Sustainability Education

POSTGRADUATE STUDENT INTERESTS IN BUILDINGS ENERGY RESEARCH, RENEWABLE ENERGY RESEARCH AND TRANSPORT RESEARCH, AS REVEALED THROUGH THEIR DEVELOPMENT OF DISSERTATION PROJECT PROPOSALS

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Keywords: buildings energy, renewable energy, transport, taught masters dissertations.

Abstract

This contribution outlines the interests of interdisciplinary minded, Level 9 (masters) students, in buildings energy research, renewable energy research and transport research, as revealed though their development of individual dissertation project proposals. The author was responsible for the delivery and co-ordination of modules in research skills, whose outcomes were the development of the dissertation proposal. The objectives of the research skills modules are outlined.

INTRODUCTION

Dublin Institute of Technology (DIT) has offered Level 9 (taught masters) programmes in various Engineering specialisations, and in Energy Management, for ten years. Core modules in research skills, in which the learner prepares a dissertation proposal, have been an element of both programmes since their inception. Experiences and reflections on the modules over the 2008-13 period have been documented [1]; in a summary of that contribution, students worked in teams, in a brainstorming environment, to develop dissertation ideas, underpinned by workshops on information literacy, technical writing, critical thinking, the research funding process, and intellectual property and patenting issues. Student teamwork was facilitated by the use of a collaborative website (wiki). The present contribution systematically outlines the relevant dissertation proposals that emerged; thus, a documentary research approach is employed.

Dissertation proposals developed 2008-2015

Dissertation proposals in buildings energy research (e.g. [2]-[8]), renewable energy research (e.g. [9]-[14]), and transport research (e.g. [15]-[18]) emerged. The author has classified the dissertation proposals received over the 2008-2015 period, according to their major theme, and some results of this classification are shown in Tables 1 and 2.

Table 1 shows that 72% of all Level 9 dissertation proposals are energy related, with 48% of all such proposals linked to themes in renewable energy research, buildings energy research and transport research. Unsurprisingly, more such proposals are developed by learners on the

MSc in Energy Management; learners on Engineering level 9 programmes have a first degree in Engineering as a requirement, and though many engineers enroll on the MSc in

Energy Management, this programme has learners with primary degrees in, for example, Quantity Surveying, Spatial Planning, Construction Management and Architecture. As a result, MSc students formulate a large number of proposals for energy applications in the built environment, partly reflecting the previous qualifications and expertise of many of these students. Generally, the MSc programme attracts highly motivated learners with an interdisciplinary ethos, and the research skills module can leverage the previous education and experience of such learners to the benefit of all.

Table 2 shows that, of the renewable energy data, proposals in wind energy are most often formulated, perhaps because of the importance of this energy solution in Ireland.

Table 1: Dissertation proposal percentage data 2008-15

Level 9 programmes	Renewable energy	Buildings energy	Transport	Other energy	Nonenergy	n
Engineering	29%	4%	4%	5%	58%	206
Energy Management	37%	15%	6%	40%	2%	253
Total	33%	10%	5%	24%	28%	459

Table 2: Renewable energy dissertation proposal percentage data 2008-15

Level 9 programmes	Biomass	Wind	Solar	Wave or Tidal	Other (e.g. hydro, geothermal)	n
Engineering	4%	10%	4%	4%	8%	206
Energy Management	7%	14%	6%	3%	6%	253
Total	6%	12%	5%	3%	7%	459

CONCLUSIONS

This short paper outlines the interests of highly educated students, with an interdisciplinary ethos, in buildings energy research, renewable energy research and transport research, as revealed though the development of their dissertation project proposals. The associated research skills modules allows the leaner to construct a research strategy, appraise and evaluate library resources, craft a literature review and develop an individual dissertation proposal, in a collaborative environment. Overall, the learning approach facilitates learnercentered education, motivates independent learning, is compatible with the student profile and background, and through peer learning unlocks previous work and learning experiences to the benefit of all learners.

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USING INNOVATIVE APPROACHES TO TEACHING SUSTAINABILITY SKILLS IN ENGINEERING AND CONSTRUCTION

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Keywords: Innovative approaches, Sustainability, Engineering, Teaching

Abstract

While there has been considerable progress in improved sustainable development through initiatives like the Paris Agreement and the consequent national commitments to reducing greenhouse gases, there is much that still needs to be achieved. Engineering and construction professionals have a significant role in this process. This role has been recognised by professional organisations such as Engineers Australia, which incorporates sustainability into its Code of Ethics, and has published both a Sustainability Policy and a guide to implementing sustainability. Teaching sustainable practices is a first step in this process. In this respect, the University of Southern Queensland has for a number of years offered an undergraduate course in Technology, Sustainability and Society, which is studied by all engineering and construction students completing a three or four-year degree qualification in the first two years of enrolment. As well as teaching environmental sustainability, this course also teaches students the wider dimensions of sustainable development, such as its political, economic, and social components. It therefore provides a foundation for the practice of sustainability that can be progressively developed by students over the balance of their study program. Over time, there have been several initiatives implemented to further develop the understanding by students of the role of sustainability in their professional careers. Such initiatives have included the use of industry based lecturers and tutors, assignments that deal with significant real world issues in sustainable development, and the use of real-time tutorials that use the University's Zoom video conferencing system. These tutorials are designed for the large number of students who study this course online. The course is supplemented at postgraduate level by courses in engineering asset and facilities management, advanced project management and risk management, all of which have a technologically based sustainability focus. The future development of this course is expected to include increased experiential learning approaches, further use of industry based lecturers, and increased use of initiatives like data analytics to better tailor the course to student needs.

INTRODUCTION

While, as shown by international initiatives like the Paris Agreement (United Nations, 2015), there has been significant progress in implanting sustainable development, much work is still required. Engineering, construction and other built environment professionals have a significant role in this process, and are increasingly required to design, operate and maintain infrastructure, buildings and systems in a sustainable manner. A sustainable outlook is also

supported by professional organisations. For example, in Australia the Code of Ethics of Engineers Australia, which is the major engineering professional organisation in Australia, requires professional engineers to demonstrate integrity, practise competently, exercise leadership and promote sustainability, which includes responsible community and stakeholder engagement; fostering health, safety and wellbeing; and balancing the needs of the present with those of the future (Engineers Australia, 2010). Such practices are supported by legislation, standards and sustainable development guidelines.

In order to develop professionals who will make sustainable development and management part of their practice on graduation, it is desirable to teach them these principles in a way that both encourages them understand the principles of sustainable development and provides them with the understanding, knowledge and skills to enable and motivate them to use sustainable practices in their professional career. While this teaching often has to be delivered in an already crowded technical study program, it should also be effective. To meet this requirement, the University of Southern Queensland has developed the *Technology, Sustainability and Society* course (University of Southern Queensland, 2018a), which is delivered in the first or second year of undergraduate engineering, construction and other built environment degree level programs, and thus provides a foundation on which learners in these programs can build an understanding of sustainability during their study program and throughout their professional career. This course is the only dedicated sustainable management course in a crowded curriculum that is primarily based on practical application of the principles of mathematics and physics. Over 80 per cent of learners in this course are external to the University. Many of these learners are employed fulltime and study part-time, and live throughout Australia and in some cases internationally, and therefore have limited opportunity to study in a classroom environment.

Because of its role as the only course in which the principles of sustainability are taught in engineering, construction and built environment programs at the University, it is important that this course be well received by those learning it. At the same time, it has traditionally not been understood well by learners because of its difference with other components of the teaching program, and has accordingly not attracted high learner evaluation scores. Recent initiatives have aimed at improving the teaching in this course through changes to the course content, assessment and delivery. The objective of the discussion in this paper is to review the initiatives against good teaching practices, to assess how well learners have evaluated them and consider how the course may be further improved.

Following a review of sustainability in engineering, construction and the built environment, this paper outlines sustainability and its professional requirements, with a focus on Australian practice, and the challenges that they pose for teaching. It then discusses three well regarded teaching practices used for evaluating initiatives in the course, poses research questions and describes the methodology for making this evaluation. There is then a discussion of how these

initiatives have improved learner evaluation of the course, reflections and lessons learnt, conclusions and a short discussion of possible future developments. This outline is shown in Figure 1, which is a conceptual framework for the paper.

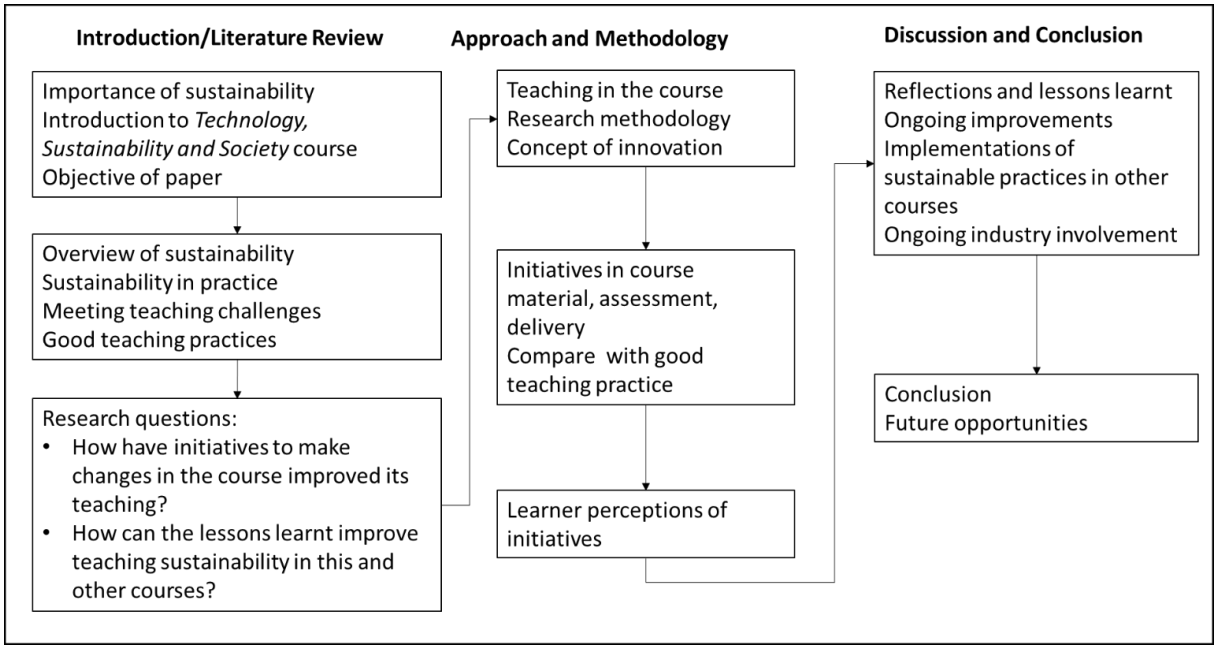


Figure 1. Conceptual Framework for Paper **LITERATURE**

REVIEW

Overview of Sustainability

The concept of sustainable development was originally defined by Brundtland (1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." It can be further defined in terms of balancing economic development, social equity and environmental protection (Drexhage & Murphy, 2010), and has over time gained increased acceptance.

The landmark Paris Agreement (United Nations, 2015), which has the goal of containing the increase in global average temperatures to 2 °C above pre-industrial levels, notes the potential issues resulting from climate change, and discusses the importance of the need for International cooperation by all countries to reduce the reduction of greenhouse gas emissions across the world. This agreement also recognises the importance, in the implementation of climate change, of respecting matters like human rights, health and related matters. Many governments, including the Australian Government, which is committed to reducing carbon emissions by 26 per cent to 28 per cent over 2005 levels by

2030 (Australian Government, 2015), have ratified this agreement. The United Nations has also published a list of 17 sustainable development goals to be achieved by 2030, in areas like

poverty, hunger, health, education, gender equality, resources (for example, water, energy and the marine environment), resilience, climate change and sustainable ecosystems; and has reported on the achievement of these goals (United Nations, 2017). This report notes that while considerable progress has been made, there is much to be done if these goals are to be achieved by 2030. It is therefore concluded that while there is progress towards meeting this wider definition of sustainability, much work is required to achieve it. Such work will require input from engineering, construction and related professions.

Understanding sustainability in engineering and built environment practice

Understanding and managing sustainable practices is therefore an increasingly significant requirement for engineering and built environment professionals. For example, Engineers Australia, which is the major engineering professional organisation in Australia, not only promotes the practice of sustainability by its members in its Code of Ethics (2010), but has also has developed a Sustainability Policy (2014), and guidelines for the principles and practice of implementing sustainability (2017) by the engineering team. These guidelines include a discussion on sustainability and what it means, and include a number of practice notes.

Australian graduate engineers are required to understand sustainable engineering practice from the point of view of their engineering discipline, and commit to sustainable engineering practices and sustainable outcomes (Engineers Australia, 2013). Experienced professional engineers are in addition expected to understand the requirements of clients and stakeholders; work to optimise social, environmental and economic outcomes of engineering products and programs; and manage risk as well as sustainability issues. They are expected to be ethical and develop safe and sustainable solutions (Engineers Australia, 2012).

Other professional organisations in the engineering and built environment professions have also recognised the role of sustainability in professional practice. For example, the Royal Institute of Chartered Surveyors (RICS), for example, has published a methodology to calculate embodied carbon (2014). The importance of sustainability has also led to the development of sustainability rating guides, such as the Green Star requirements for buildings (Green Building Council Australia, n.d.). Industry is also developing sustainable management requirements, such as the “Built to Perform” industry led pathway to a zero carbon ready building code (Australian Sustainable Built Environment Council, 2018).

On the other hand, while an Australian study found that sustainable practices are accepted by many industries (Thomas, Barth & Day, 2013), it was observed that the importance of sustainability is not uniform across the engineering and built environment professions. Similarly, a survey of recruiters in 100 United States construction companies found that environmental awareness was rated below other managerial and professional skills (Ahn et al.,

2012). Thus, there are still differences in views with respect to the importance of sustainable practices across the industry and professional spectrum.

In summary, the understanding of sustainability in engineering, construction and other built environment disciplines is developing over time. As a result, courses like *Technology, Sustainability and Society* (University of Southern Queensland, 2018a), which aim to develop and embed the skills of sustainability in engineering, construction and other built environment professionals, are important in the education of such professionals.

Meeting the challenges in teaching sustainability in engineering and the built environment

Given the requirement for engineering and built environment professionals to possess knowledge and skills with respect to sustainable practices in the execution of their profession, it is highly desirable to provide them, during their professional education, with the knowledge and skills to incorporate sustainability into their professional responsibilities. This process provides both challenge and opportunity.

As a result of an increasing overall focus on sustainable practices, there is an increase in teaching sustainable practices to engineering students (Lu and Zhang, 2014). For example, the Engineering Department of the University of Cambridge has recognised the role of sustainable practice in engineering (Fenner et al., 2005). Furthermore, it is important to recognise the complexity of the education of engineering and construction professionals in a crowded in a crowded curriculum and to provide a rounded education (Zhang et al., 2012). A related issue in teaching sustainability in engineering and the built environment is that the social components of sustainability have the potential to be not very well understood by learners and therefore may not be learnt as well as its environmental and economic aspects. ValdesVasquez and Klotz (2011) have addressed this area through using a conceptual model derived from the dimensions of social sustainability. Other approaches to this problem have included life-cycle thinking in construction materials and methods (Lin, Levan and Dossick, 2012).

Therefore, while sustainable practices have the support of engineering and related professional organisations, and are being increasingly adopted by industry, there are challenges in teaching them. Such challenges can include the requirement to fit their teaching into crowded study programs, and ensuring that social aspects of sustainability are taught as well as its environmental and economic aspects. In order to meet these challenges, it is desirable to design, develop and deliver courses well and employ good teaching practices. Such teaching practices include student centred learning, authentic assessment and experiential learning. Student centred learning, or learning that focuses on what the student does, specifies the desired outcomes (or objectives), uses assessment that is criterionreferenced to the

objectives, and encourages learners to engage in appropriate learning activities that encourages learners to undertake learning in a way that achieves the objectives. It thus uses an aligned system of instruction that provides maximum consistency through the system (Biggs, 1999). Authentic assessment (Gulikers et al., 2004) is a form of performance assessment and accordingly is a form of criterion-referenced assessment aligned to academic instruction. It requires learners to demonstrate their competencies in a setting that resembles professional practice, and can be divided into five dimensions five dimensions - task, physical context, social context, assessment form and criteria. In its simplest form, experiential learning can be considered learning by doing or experiencing. This method of learning can be described through the experiential learning cycle developed by Kolb (1984) of a concrete experience by the learner, reflective observation on that experience, abstract conceptualisation or drawing conclusions about experiences, and active experimentation. All three approaches have the potential to be linked.

In examining the use of innovative approaches and other initiatives in the ongoing development and improvement of the *Technology, Sustainability and Society* (University of Southern Queensland, 2018a), and to link the use of these approaches with good teaching practice, the following two research questions have been developed:

- How have initiatives to make changes in the course improved its teaching?
- How can the lessons learnt from implementing and improving the teaching of sustainability in the course improve teaching sustainability in this and other courses?

APPROACH AND METHODOLOGY

Description of Teaching in the *Technology, Sustainability and Society* Course

The *Technology, Sustainability and Society* course (University of Southern Queensland, 2018) is delivered in each of Semesters 1 and 2, and over the shorter Semester 3, which spans the summer period. On-campus learners are enrolled in Semester 1 or 2, and study at either the main University campus at Toowoomba, Queensland, Australia, or the Springfield Campus, near Brisbane, Queensland. Online learners, who comprise over 80 per cent of all enrolments, can study in any semester. This course teaches sustainable engineering and built environment practices, and the professionally significant related topics of social issues and their impact on their work and the communities that they serve. To achieve these goals, it addresses the history of technology, sustainability, environmental impact assessment, politics and power, the economy, models of society, cultural impacts, the legal framework and sustainable engineering management. It is assessed by two assignments (worth 10% and 20% of course marks respectively) and a two hour closed book written examination (worth 70% of course marks). Emphasis is placed upon students being allowed to develop their own opinions on ideas and concepts, using non-technical written English, to a reasonable ability.

The teaching approach used in *Technology, Sustainability and Society* (University of Southern

Queensland, 2018a) is based on blended learning (University of Western Sydney, 2013), which combines both on-campus teaching to learners attending classes at the University and online delivery to learners studying externally to the University. Delivery of the course is underpinned by an online Study Desk that all learners can access. This Study Desk contains written course material, lecture slides and other aids such as recorded lectures, readings, postings of useful material and video presentations. It is structured to meet learner requirements, and allows learners to post queries for response by teaching staff or other learners. It is also the portal for assignment submission. Tutorials and reflective exercises supplement course delivery. There is a continual improvement process facilitated by learner feedback and evaluation of the course and its teaching at the conclusion of each semester.

RESEARCH METHODOLOGY

This paper aims to address the research questions proposed as follows:

- Selected innovative approaches (or initiatives) aimed at enhancing the content, assessment and delivery of this course are discussed from the point of view of good teaching practices.
- This discussion is followed by an assessment of the impact of these initiatives, considered as a group, on learner evaluation of the course and its teaching at the end of each teaching semester, followed by reflections and lessons learnt, and a conclusion.

The definition of "innovative approaches" (or initiatives) used for this study is based on the definition of "innovation" by the Australian Government (2017), which is "Innovation generally refers to changing processes or creating more effective processes, products and ideas." This definition is supported by the Oslo Manual (OECD and Eurostat, 2005), which defines an "innovation" as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations." Therefore, in this paper an innovative approach or initiative is considered as one that achieves significant improvement.

DISCUSSION OF INNOVATIVE APPROACHES USED TO ENHANCE THE COURSE

Ongoing Improvements in Course Material

While this course has always had a focus on the environmental, political, economic and social dimensions of sustainability, for many years it used a traditional approach to teaching, in which learners completed assessment questions that required direct answers. Over time, additional material has been added, such as the extension of the discussion on social sustainability to the understanding indigenous cultures, including respect for their county and artefacts, and the

use for tutorials of high quality videos (for example, about the lives of great economists), with a view to prompting learners to think. Such initiatives are designed to develop an ongoing interest in sustainable practices, and encourage independent thinking. It accordingly addresses learner engagement and student centred learning.

Changes in Assessment Methods

While assignments and the examination in the T*echnology, Sustainability and Society* course (University of Southern Queensland, 2018a) have always had a strong sustainability focus, they have changed in recent offers of the course to a more student-centred learning approach based on authentic assessment (Gulikers et al., 2004) and experiential learning (Kolb, 1984). Assignments now require learners to address environmental, economic and social challenges in major projects in globally sensitive industries, such as resource exploitation, agriculture and forestry. The first assignment has been accordingly changed to seek viewpoints on topic set for the assignment from representatives of three stakeholder groups likely to be involved in the project, while the second assignment requires learners to provide an up to 2000 word Sustainability Assessment Report for the same project that was used for the first assignment. Each assignment uses an authentic assessment approach based on a real project that is researched by learners and is accordingly designed to internalise in learners the principles of sustainable management. Feedback on the answer to the first assignment allows learners to engage in experiential learning through reflecting on assignment marks and comments, drawing conclusions that can be applied to the second assignment and implementing them in the answer to this assignment. This approach has replaced a traditional approach in which learners were asked to write short essays or perform economic calculations.

Developments in Course Delivery Approaches

One of the initiatives in delivering this course has been to provide high definition live video lectures and tutorials, often delivered at the end of the working day, that enable the 80 per cent of online learners in the course to experience real-time teaching. The University has selected the Zoom video technology (Australia's Academic and Research Network, 2017) for this purpose. This approach facilitates live interaction between the lecturer or tutor and up to 100 participants, permits high quality presentations of material, and facilitates interaction between all parties connected to the system. The discussion is recorded for the benefit of those who cannot attend. This technology was first used in the 2017 offers of this course. Another well-received recent initiative, which also uses this technology, has been the use of industry based guest lecturers, using lectures and interviews. In conclusion, while interactive video conferencing is not new, the use of high definition interactive video sessions that can be used in real time and involves learners living remotely from the University facilitates learner engagement, and student centred learning through allowing learners to listen to the views of other participants and providing input into the discussion. Through this engagement process, learners, through interacting with the teaching team and each other engage in an experiential learning process (Kolb, 1984).

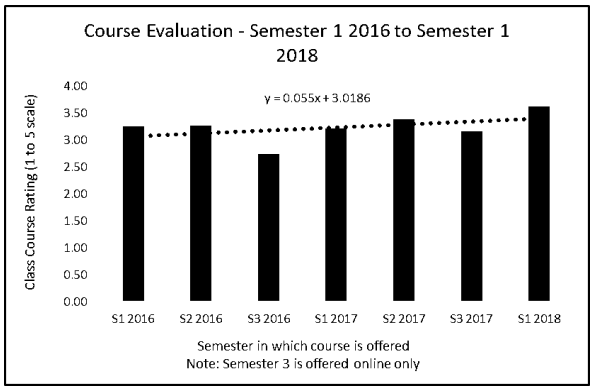
In summary, the use of these initiatives in delivering this course has achieved improvements to its teaching and ongoing learner engagement. The relationship of these initiatives to the example good teaching practices discussed in this paper are shown in Table 1.

Table 1, Relationship between Course Initiatives and Good Teaching Practice

Example Course Initiative	Relationship to Good Teaching Practice
Improvements in course materials	Learner engagement, student centred learning
Changes in assessment methods	Authentic assessment, experiential learning
Course delivery development	Learner engagement, student centred learning, experiential learning.

LEARNER PERCEPTIONS OF THE INITIATIVES

While the initiatives discussed in this paper have each resulted in an improvement in this course, they have, when combined, resulted in a considerable improvement in learner perceptions of the course, as evidenced by end of semester feedback to the University's MyOpinion system for learner evaluations of courses and their teaching. Figure 2 shows a marked increase in course evaluation by learners over the period from Semester 1 2016 to Semester 1 2018. This graph shows that overall learner satisfaction has increased from 3.26 on a scale of 0 to 5 for the Semester 1 2016 offer of the course to 3.63 for the Semester 1 2018 offer, with an overall positive trend rate of 0.055 points per semester, with an intercept value of 3.02. The improvement in the Semester 3 (Summer) semester result between 2016 and 2017, when all learners in the course studied online, is quite significant, and shows an overall improvement over the year of 0.42 points (from 2.74 to 3.16). Teacher evaluation has similarly shown an increase in average student satisfaction, but at a greater rate, with an overall positive trend rate of 0.113 points per semester, with an intercept value of 2.76. As both results show a measurable positive increase in learner satisfaction with the course and its teaching as a result of implementing the initiatives discussed in this paper, the result demonstrates that the initiatives discussed in this paper have (both singly as a combined group) been quite innovative.



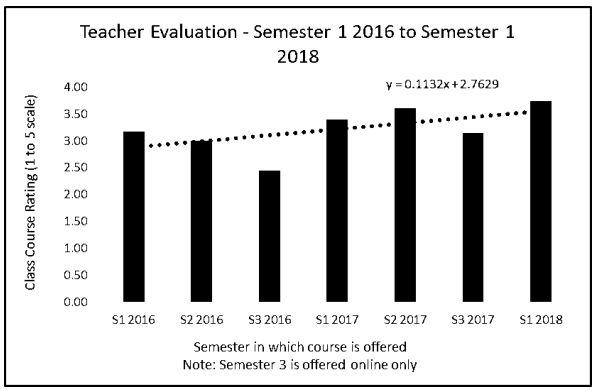


Figure 2. Learner Satisfaction Scores - *Technology, Sustainability and Society*

REFLECTIONS AND LESSONS LEARNT

It has been demonstrated that implementing ongoing positive development of the *Technology, Sustainability and Society* (University of Southern Queensland, 2018a) has facilitated learner engagement, student centred learning, authentic assessment and experiential learning; and improved learner satisfaction with the course and its teaching. At the same, time, there is still much work to be performed to achieve further understanding of the material in this course by learners, and improve their views of the course and the material taught in it. This task will be achieved through a strong ongoing commitment to this process.

While the improvements to this this course have achieved a significant positive change in the teaching of sustainability knowledge and skills at the introductory level, it is also important to undertake ongoing development of the sustainability knowledge and skills of engineering, construction and other built environment professionals. The University has taken a number of steps in this process. For example, several undergraduate courses incorporate sustainable practices, sustainability assessment is required in the final year project undertaken by learners, and there is a strong emphasis on sustainable practices in postgraduate courses in areas like advanced engineering project management, asset management, and the management of technological risk (University of Southern Queensland, 2018b). There is also an opportunity to undertake research in advanced applications of sustainability in engineering, construction and related disciplines.

Part of the process of teaching sustainable development and management skills is to engage potential employers of graduates in the teaching process. This engagement can be facilitated by close relationships with professional associations such as Engineers Australia, which as previously discussed is committed to sustainable practices and can influence industry. The use of industry based lecturers in this course has been a positive step in this process.

CONCLUSION

It is concluded that the approaches taken to improve this course have achieved an ongoing measureable overall improvement in learner evaluation of the course and it teaching. This positive change has occurred as a result of implementing simultaneously a number of positive initiatives, which have been aimed to improving the course content, learner engagement, learning and assessment. Considered both separately and together, these initiatives, each of which has made a difference to the teaching in this course, can be considered quite innovative.

While the research discussed in this paper is limited to discussing selected initiatives in this course and its teaching, there is potential for considerable further research in this topic area, including the wider teaching of sustainable practices in all levels of engineering, construction and other built environment programs. There is also considerable opportunity for further developments and initiatives in the way in which this course teaches sustainability. For example, course content can be developed through including future topics like resilience and the impacts of advances in materials and information technology on sustainability and its practices. Similarly, the use of experiential learning and improved assessment have the potential to be further developed. The potential of video communication to aid engagement in live dialogue with online learners in real time, and improved collaborative processes, can be further explored. Improved use of learning information systems like data analytics to monitor learner engagement may also be able to improve course engagement and learning. There is in addition expected to be considerable benefit in further embedding sustainable practices in undergraduate and postgraduate courses, as well as in research programs.

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RELEASING AN EDUCATIONAL ANDROID APP

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Keywords: Mobile app development, e-learning, sustainability education, domestic heat loss.

Abstract

This paper explores the process and challenges of creating an educational app for android devices. The Heat Loss Calculator app was initially conceived to allow researchers to quickly calculate building heat loss by entering the U-values of different building element fabrics. Selecting lower U-values equates to the various insulation improvements which can potentially reduce heat loss and improve energy efficiency. During early development it became clear that the app would also be a useful learning tool for students. Therefore, it was designed with this wider audience in mind, with the intention of publishing it in the public domain. Issues encountered during development and some that became apparent after release on the Google Play Store will be discussed. The user experience will be evaluated by means of an online survey of students and by using the app in a group session in the classroom. The feedback will be examined to inform how the app can be improved.

INTRODUCTION

In 2016 Leeds Sustainability Institute pursued the idea to embed current research experience into an educational app for android devices. Its purpose is to help researchers, students and professionals explore the potential energy efficiency of different building element fabrics. The Heat Loss Calculator introduces the concept of calculating heat loss from the varied materials used in house building. The aim of the app is to quickly calculate building heat loss and how much various insulation improvements could potentially reduce it by reducing U-values.

In the Calculator page, the user can enter values in m^2 for the size of the areas of the surfaces of a building. U-values are initially displayed at a worst-case scenario of having no insulation; the user can select other U-values from drop-down menus. When the “Heat Loss” button is pressed, the areas are multiplied by the U-values and total heat loss is calculated, displayed next to the “TOTAL (W/K)” text. The app features a user guide in which terms used in the calculations are explained. Links are provided to the relevant UK Building Regulations and teaching resources. This concurs with the ideas of Zydney and Warner (2016) to ensure sufficient background material and extra learning is supplied within the app or users directed to other useful sources.

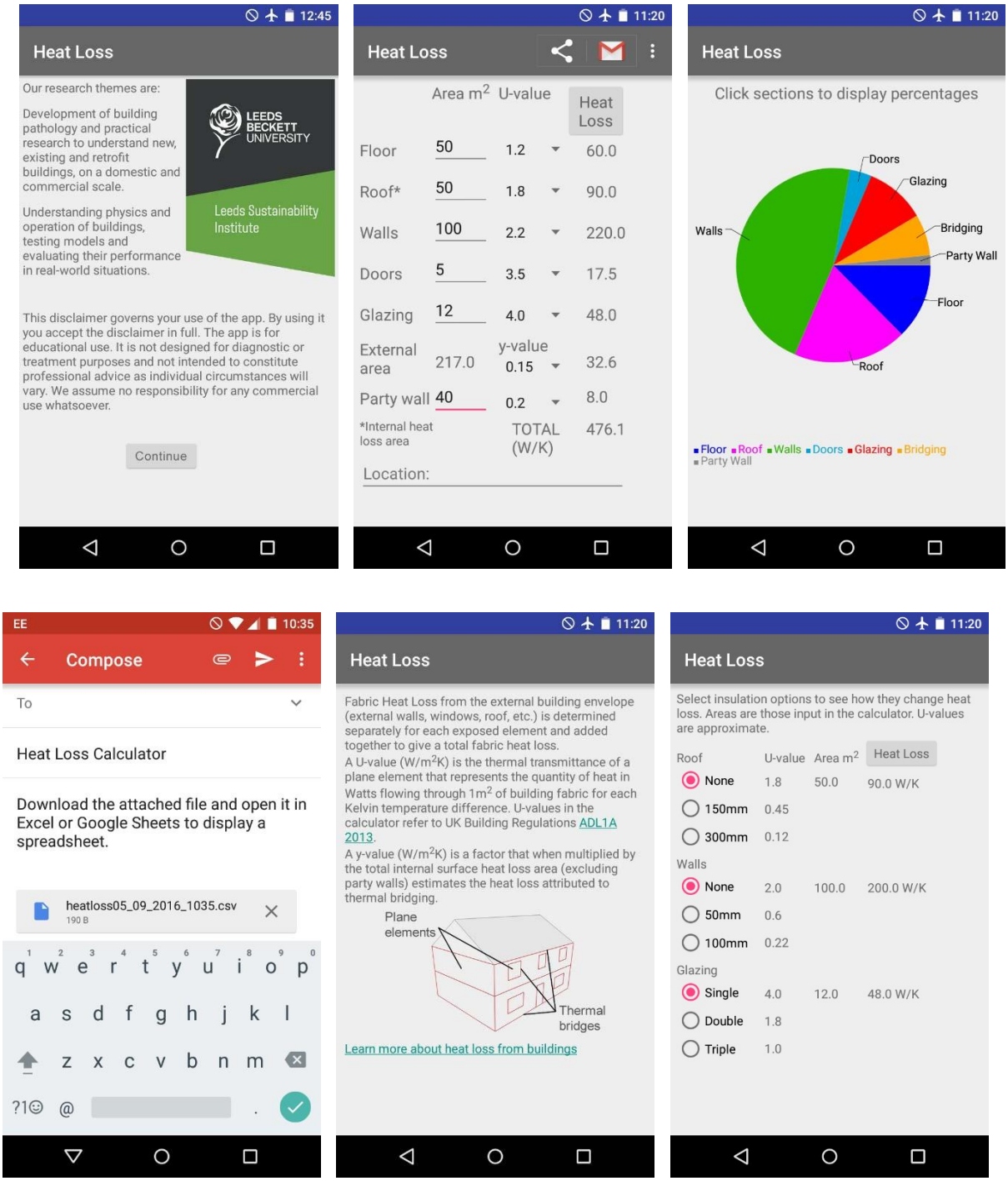


Figure 1. Screenshots of an early version of the Heat Loss Calculator app

A reliable method of sending data out from the app via email was sought. It was decided to achieve this by writing a new Comma Separated Value file (.csv) to a “Public” folder within the Android Operating System (OS) every time any of the values were changed in the calculator.

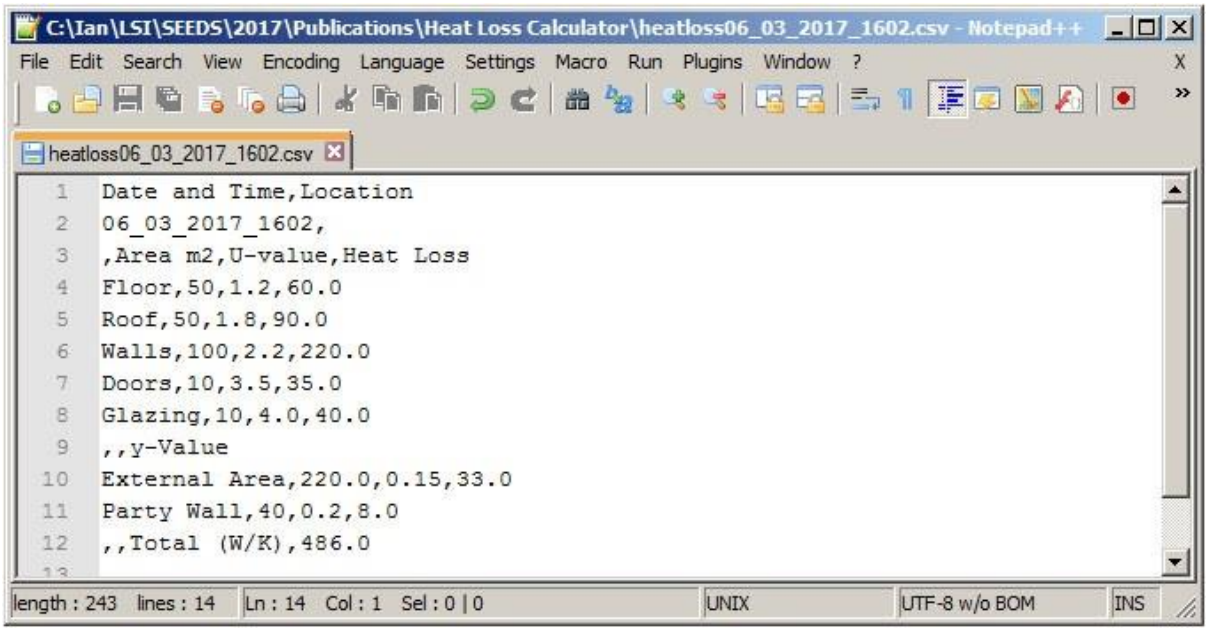
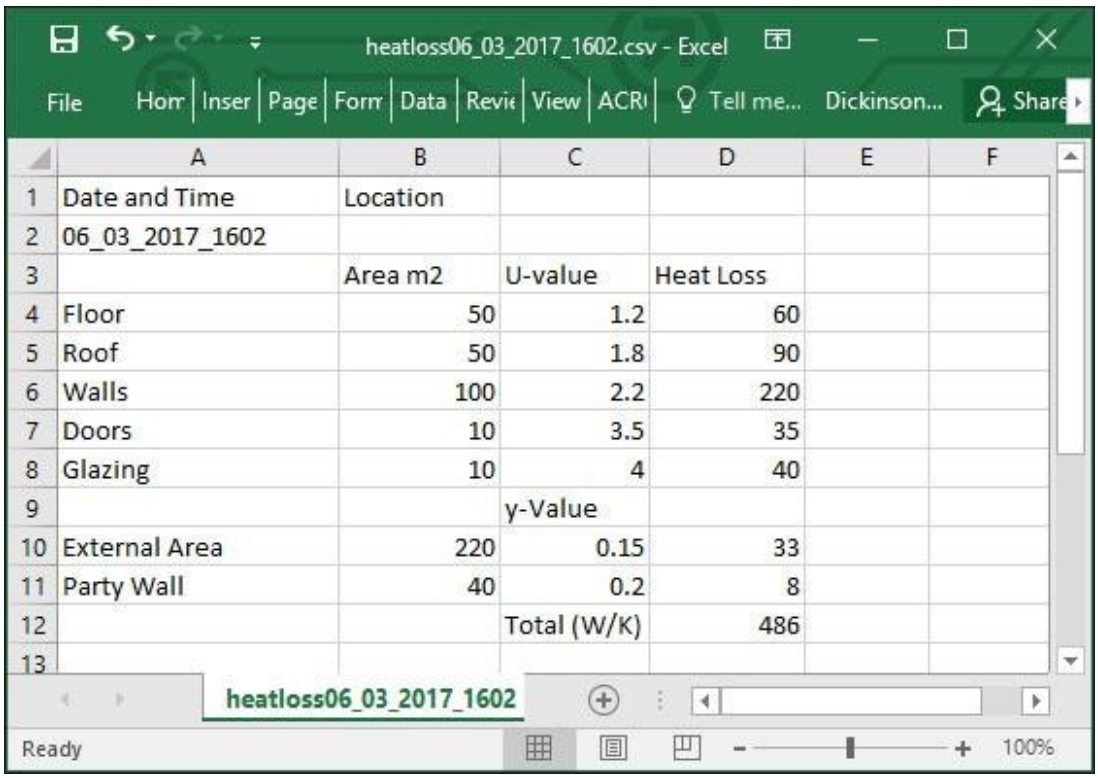


Figure 2. Java code within the app writes a .csv file when values are changed in the calculator.



	A	B	C	D	E	F
1	Date and Time	Location				
2	06_03_2017_1602					
3		Area m2	U-value	Heat Loss		
4	Floor	50	1.2	60		
5	Roof	50	1.8	90		
6	Walls	100	2.2	220		
7	Doors	10	3.5	35		
8	Glazing	10	4	40		
9			y-Value			
10	External Area	220	0.15	33		
11	Party Wall	40	0.2	8		
12			Total (W/K)	486		
13						

Figure 3. Once imported into Microsoft Excel or Google Sheets, the .csv file is displayed as a spreadsheet.

The folder structure of the android operating system was examined to see which would be the most suitable folder to write the file to. The 'Downloads' folder was initially chosen, as this existed in all the android phones and tablets that the app was tested on prior to release. Also, it is a “Public” folder, i.e. it can be written to by apps.

Alpha testing was carried out on various android phones and tablets used by colleagues. The Webopedia web site defines alpha testing as, "A very early version of a software product that may not contain all of the features that are planned for the final version. Typically, software goes through two stages of testing before it is considered finished. The first stage, called alpha testing, is often performed only by users within the organization developing the software."

A problem was identified only after the initial release of the app on the Google Play Store. The 'Downloads' folder is not in the same location within the file structure of all android devices. The app crashed when the device attempted to open the calculator if the Downloads folder wasn't in the location specified by our code. We withdrew the app from the Play Store until a solution could be found. A reliable Public folder location was found to be the Cache folder of the app. A 'Try/Catch' method was added to the code as a backup in case the file writing failed. The app initially attempts to run the 'Try' method of writing the file. If it fails, then the 'Catch' method writes the calculator data as text into the text area of the email.

Beta testing was then carried out through the Play Store with a group of approximately 10 friends and colleagues who had expressed an interest in the app. The Webopedia web site defines beta testing as, "A test for a computer product prior to commercial release. Beta testing is the last stage of testing, and normally can involve sending the product to beta test sites outside the company for real-world exposure or offering the product for a free trial download over the Internet." The beta test group all successfully installed the app and no crashes or bugs were reported. In retrospect it would have been wise to have performed beta testing prior to releasing the app on the Play Store.

Inukollu et al. (2014) argue that one of the reasons for low quality apps from a Software Development Life Cycle point of view is that not enough testing is done. "App developers are more fixated on functional aspects of the app and hence they sometimes ignore security and performance testing, which are the key components of any app." Lessons were learned by our team in the importance of beta testing the app. However the major variations in screen size and pixel density/ screen resolution between the many types of Android devices presents a challenge for the developer to test and publish the app in a format that is optimised for all users. Graphics and text can be defined with code to display at different sizes depending on the device. To an extent this can be modelled on android devices of varying screen dimensions and screen densities in the Android Studio software. However, after releasing the app and testing it on the phones and tablets of colleagues, an issue that had not previously been considered became apparent. Android has various settings for the display of font size. If the font size was set to maximum, the launch button was pushed off the bottom of the screen. If it was set to minimum, then text and graphics were pushed out of place. A compromise was reached to make the app screens display correctly across all devices. With the constantly evolving nature of mobile devices, this will remain an issue.

A poor review was posted on the Play Store stating, "*The home page freezes and there's no links to do anything*."

The Play Store user account allows the account holder to see the type of device on which the reviewer installed the app. The app had been tested prior to release on the same model of device used by this reviewer and the error described was not observed. The W3C Mobile Accessibility Guidelines state that a variety of methods allow the user to control content size on mobile devices with small screens. At the browser level these methods are generally available to assist a wide audience of users. At the platform level these methods are available as accessibility features to serve people with visual impairments or cognitive disabilities. The methods include the following features at the OS level:

- Set default text size (typically controlled from the Display Settings)
- Magnify entire screen (typically controlled from the Accessibility Settings).
- Magnifying lens view under user's finger (typically controlled from the Accessibility Settings)

We presumed that the error may have been caused by one of the reasons above. Perhaps the user's OS settings had pushed the 'Continue' button off the bottom of the screen. The button was moved higher up the page and the app was re-published. We posted a response to the review on the Play Store stating: "*Sorry to hear you've had problems with the app. We've moved the 'Continue' button higher up the home screen in case it was not visible on your device. Thanks for your feedback*." Two months later another poor review was posted on the Play Store stating, "*didnt (sic) do anything just stayed on home page rip off.*" Clearly, the 'Continue' button on the home screen was either not being displayed or not working on some devices. It was replaced with a Menu dropdown link from the Home page to the Calculator page, which has hopefully fixed the problem.

Ma et al. (2103) argue that, "The usability of mobile applications is critical for their adoption because of the relatively small screen and awkward (sometimes virtual) keyboard, despite the recent advances of smartphones." Because traditional laboratory-based usability testing is often tedious, expensive, and does not reflect real use cases, they propose a toolkit that embeds into mobile applications the ability to automatically collect user interface (UI) events as the user interacts with the applications.

Other reviews of the app included the following:
"*…i found the fact that you input your own u-values a bit confusing and think it would be helpful if there was at least a U-value guide (cavity wall U-value = X)…*" "*I found the app very confusing. Could give more details of how to use and what each element is*."

The work by Zydney and Warner (2016) showed that "Researchers need to make more explicit connections between the instructional principles and the design features of their mobile learning environment in order to better integrate theory with practice". This reasoning informed our decision to design the app for surveying researchers and students, who have an understanding of U-values and building construction. There is a link provided within the app to the UK Government document "Conservation of fuel and power: Approved Document L", which states building regulation in England setting standards for the energy performance of new and existing buildings. The various documents linked to from this web page give U-values

for the wide variety of building materials used in dwellings and non-domestic buildings for both existing and new-build construction. The information provided is of a technical nature, thus it is a valid criticism of the app that it is not easy to use without some knowledge of the subject. Inukollu et al. (2014) argue that various causes for the failure of an app include minimum/no knowledge of user demands and expectations and a lack of knowledge of the target audience. However, reviews of the app demonstrate that focussing solely on the target audience can result in a negative experience for those who fall outside the target audience.

METHODOLOGY

The app is being used as a teaching tool by Level 5 students on the Detail Design, Planning & Property Development module of the BSc (Hons) Building Surveying within the School of Built Environment & Engineering. The module requires students to explore the roles of a building surveyor in relation to planning, design and finance with regards to a commercial property acquisition and to a specific site development. Students are instructed to use the app to carry out a heat loss assessment of the building as part of an overall building survey.

Ownership of android devices among the student group

A presentation of the app was made to the student group. It was found that of the 15 students who attended the lecture, only two had android devices. The rest were using iPhones. This was surprising, as according to the International Data Corporation (IDC), Android held an 85 percent share of the worldwide smartphone market in the first quarter of 2017, whereas Apple held a 14.7 percent share.

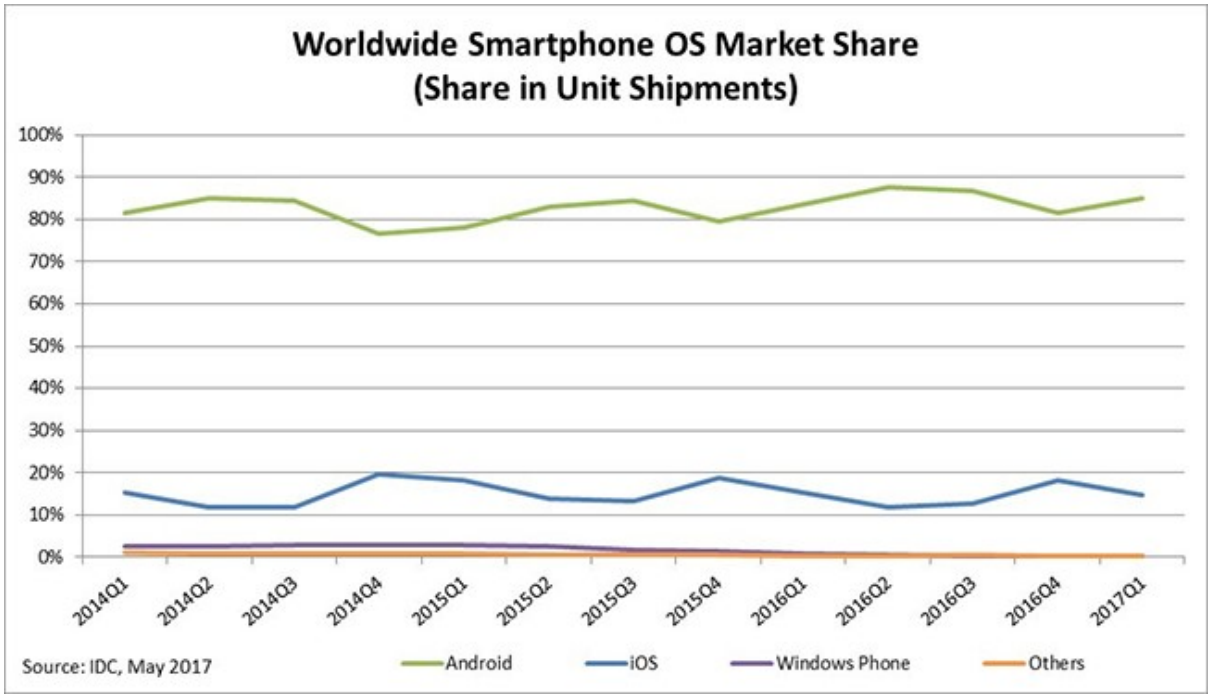


Figure 4. Worldwide Smartphone OS Market Share. Source: IDC, 2017

A method of giving access to the app to students not having access to android devices is to use the Bluestacks android emulator, which can run on a computer running the Windows operating system. However, this is not an ideal solution as it requires the user to either have a Windows laptop with them while they are performing the building survey, or otherwise making written notes of the dimensions of the building and inputting them later into the Bluestacks emulation of the app.

The ideal scenario would be to rebuild the app for the Apple mobile device operating system, iOS by rebuilding it in X Code. Google announced the open source release of J2ObjC, a Google-authored translator that converts Java classes to Objective-C classes for iPhone/iPad applications. This method was investigated as a method of reducing development time, however it became clear that one must learn how to use the iOS SDK (Software Development Kit) in order to create the Graphical User Interfaces (GUI). Currently, time constraints make this impractical for our team, however it may be pursued in the future.

A solution for the developer faced with implementing mobile apps across multiple platforms may lie in HTML5. Sheldon (2018) states that, "Many organizations are turning to HTML5 mobile application development to streamline the implementation of apps and reduce cost and complexity. Under the right circumstances, HTML5 apps provide an enterprise with a simple alternative to native app development, especially as more HTML5 development frameworks emerge."

Online survey

An online survey was created to obtain student feedback. An invitation to complete the survey was sent to all students studying the Surveying module within the School. This produced no responses. A further attempt was made to generate some response by asking the 15 students in the group mentioned above during the presentation. This produced four responses, providing the comments shown in Figure 5.

Did the app enhance the written guidance in the module document and on MyBeckett (the University's Virtual Learning Environment)?	• Somewhat, it clarified how to use it more. • Definitely, the written document was much easier to follow and understand after the app was used. • Gave me a greater understanding of thermal bridging in accordance with plane elements.
Please evaluate your experience of using the app.	• Further explanation within the app of what the roof area encompasses, as well as what the external area is, before the calculation this is confusing as you think you need to enter an amount. • Easy to follow, straight forward and simple. Quite difficult to find and install if you're not on android. • It's easy to use and downloading the app was straight forward.

Did you experience any difficulties in installing or using the app?	• • Yes, it wasn't easy with Bluestacks. • Quite a long process installing the app for now android users. It's easy to use and downloading the app was straight forward.
How could the app be improved?	• More choice of u values. • The app is good, I just think it could look more aesthetic to the eye.
What developments might you or others find useful?	• More u values • Change of resolution, the page looks too busy.

Figure 5. Online survey responses

Although this feedback was informative, responses were very brief and did not give a great deal of insight into how the students are using the app. An improved student response was clearly required to gain useful feedback for research and to draw any meaningful conclusions.

Group work

During earlier work trialling a virtual reality surveying application (available on the Virtual Site website), discussed by Ellis et al. (2006), one tutor had used the exercise in a student group session, which he believed to be beneficial, stating, "*Working at the PC can be very lonely for a student. It [the surveying exercise] seemed to work better in class, as it promoted a lively discussion. Whilst I have no evidence to back this up, I think that some of these students went back to the exercise after class and gained more from it*." There has been much research on group work, and as an example Kitzinger (1995) gives some of the benefits of focus groups. We decided to use a classroom group work approach to gain feedback for the Heat Loss Calculator app. We did not intend to conduct rigorous focus groups for this work, but found that using a final year cohort of undergraduate students, split into six groups with facilitators shows some of these benefits, such as a greater willingness to discourse, as suggested by Kitzinger (1995).

A brief initial presentation of the app was made to a group of Level 6 students studying the Interprofessional Studies module. Students who take the module are from BSc courses of Architectural Technology, Building Surveying, Quantity Surveying and Construction Management (Project Management). They have all studied U-values and heat loss from buildings during Level 4 of their courses. Several weeks later, the students used the app in group work and their reactions were recorded with their permission with audio recording devices (android apps and MP3 recorders). Out of a group of approximately 50 students, only one student owned an android phone, the rest were using iPhones. Prior to the session, the app had been installed on five android tablets; the one student with an android phone also installed the app at the start of the session. The students were split into six groups of approximately eight students in each group; academic members of staff briefly demonstrated how to use the app and then let them continue doing a heat loss survey, with occasional assistance from staff.

Student responses during group work

Group One

After the group had been using the app for several minutes and had entered some U-values, they were asked by a member of staff if they had any comments. One student said, "*I'm not quite sure I understand when the app would be used. Do you design it (the building) and then do the calculation (with the app)?"* It was explained that the app was designed for University researchers doing property surveys, to quickly show householders where heat loss was coming from. Once this was explained to the student, the purpose of the app became clear. A description of the app is given on the Google Play Store, however it had not been envisaged that someone would try to use the app without having read the description.

Because of this comment and reviews of the app on the Play Store, we decided to provide some basic instructions in the introductory text on the Home page.

Group Two

A student suggested the app would be improved by the incorporation of a U-value calculator, as the user might not know the U-values of the building being surveyed. As discussed in the Introduction section of this paper, links are provided within the app to UK Government documents in which U-values are given for the wide variety of building materials. A U-value calculator is fairly complicated and probably needs to be published as a self-contained app. U-value calculators are available online or as apps; some are published by construction/ insulation companies. Although linking to one of these would improve the usability of the app, it would imply endorsement of the company. If the UK Government were to publish such a calculator, that would be an ideal resource to link to from within the app. The text of the Home page of the app was amended to advise the user that U-value calculators are available online.

Group Three

Reluctance among the group to using android devices (as opposed to the iPhones which the vast majority of the students own) was shown by a student's first reaction to looking at the app being, "*I don't know how to use an android*." When the students were discussing with an academic colleague (an iPhone owner) how to switch between apps to check if the audio recorder app was running on the android tablet another student said, "*It's so un-user friendly*." It could be argued that this reaction is because over many years, students have learned how to operate Apple devices, rather than there being an inherent problem with android devices. A long-term android user might have the same reaction upon first using an Apple device. When this group had finished using the Heat Loss Calculator app, one of the students said, "*Shall we stop recording?*" at which point one of the students switched between the open apps and the recording stopped. One might conclude that android is not "so un-user friendly", once the user becomes familiar with it.

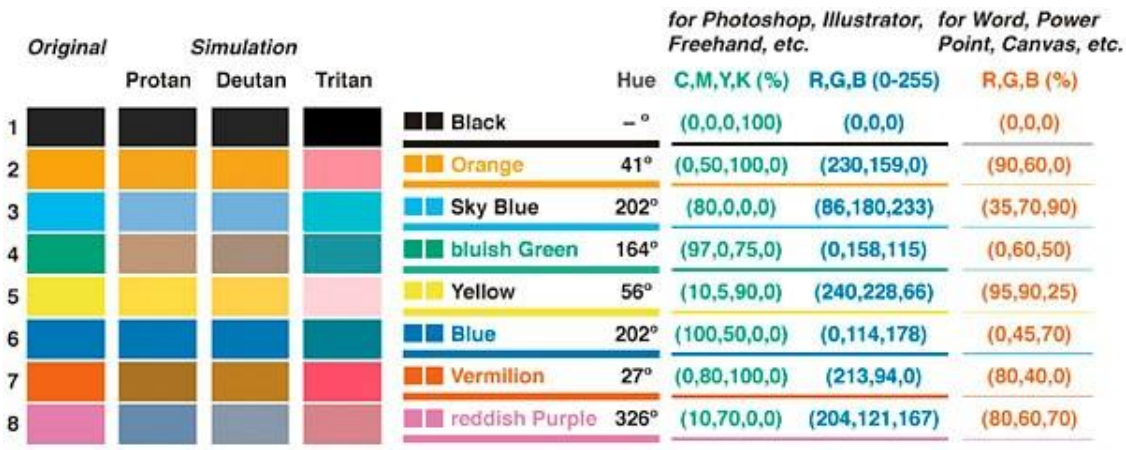
Prior to the group work, the Calculator page of the app had labelled the calculated total area field as "External Area". A change was made to the app after a student pointed out that "*When you're working out thermal bridging… you would never do it from your external dimensions*." Though a heat loss survey can be performed with either internal or external dimensions, to

avoid being unnecessarily specific about this, the label was changed to “Total Area” and a footnote was added to explain that the “Total Area” excludes party walls.

Group Four “*Because you can’t get the app on the (Apple) App Store, I used the Bluestacks emulator. But it just would not work for me. So if I had a criticism it would be that it is not available for Apple. I’m guessing there are cost implications there*.”
“*The pie chart would be better if the percentage was (displayed) next to the name (i.e. next to the section labels) on the pie chart, rather than having to click on the sections to see it. And have a Back button rather than press the (navigation) button in the actual app*.” To which another student responded, “*I think that’s purely because we are iPhone users. I think Android users would instinctively use that button to go back*.”

Group Five
“*The one thing I’d say would have to be changed (to improve the app) would be to make the drop-down U-values editable*.” In the original release of the app, the U-values in the dropdown menus were set at pre-determined values. Construction industry/ insulation professionals have also suggested making the U-values editable. The method of creating the drop-down menus was with android Spinners, which call pre-determined values from an
.xml file. These values cannot be altered at runtime. It will be investigated to discover if it is possible to make values editable with a different android method.

Group Six
Referring to the pie chart, students commented, “*The colours look a bit weird. A bit too vibrant*.” “*A bit bright*.” W3C Web Standards (Accessibility Requirements for People with Low Vision) state that, “Many people with low vision have extreme sensitivity to light (called photophobia). Bright light makes it difficult or impossible to see, and causes eye pain and headaches.” As a result of this student feedback and after reading the W3C Web Standards, we decided to reduce the brightness of the pie chart colours. Further reading highlighted issues associated colour blindness for comprehending pie charts. Okabe and Ito (2018) have proposed a set of colors that is unambiguous both to colorblinds and non-colorblinds, displayed in Figure 6.



	Hue	for Photoshop, Illustrator, Freehand, etc. C,M,Y,K (%)	R,G,B (0-255)	for Word, Power Point, Canvas, etc. R,G,B (%)
Black	– °	(0,0,0,100)	(0,0,0)	(0,0,0)
Orange	41°	(0,50,100,0)	(230,159,0)	(90,60,0)
Sky Blue	202°	(80,0,0,0)	(86,180,233)	(35,70,90)
bluish Green	164°	(97,0,75,0)	(0,158,115)	(0,60,50)
Yellow	56°	(10,5,90,0)	(240,228,66)	(95,90,25)
Blue	202°	(100,50,0,0)	(0,114,178)	(0,45,70)
Vermilion	27°	(0,80,100,0)	(213,94,0)	(80,40,0)
reddish Purple	326°	(10,70,0,0)	(204,121,167)	(80,60,70)

Figure 6. Colorblind barrier-free color pallet

This set of colours also fulfil the requirement of not being excessively bright, so they were used for the pie chart in the app.

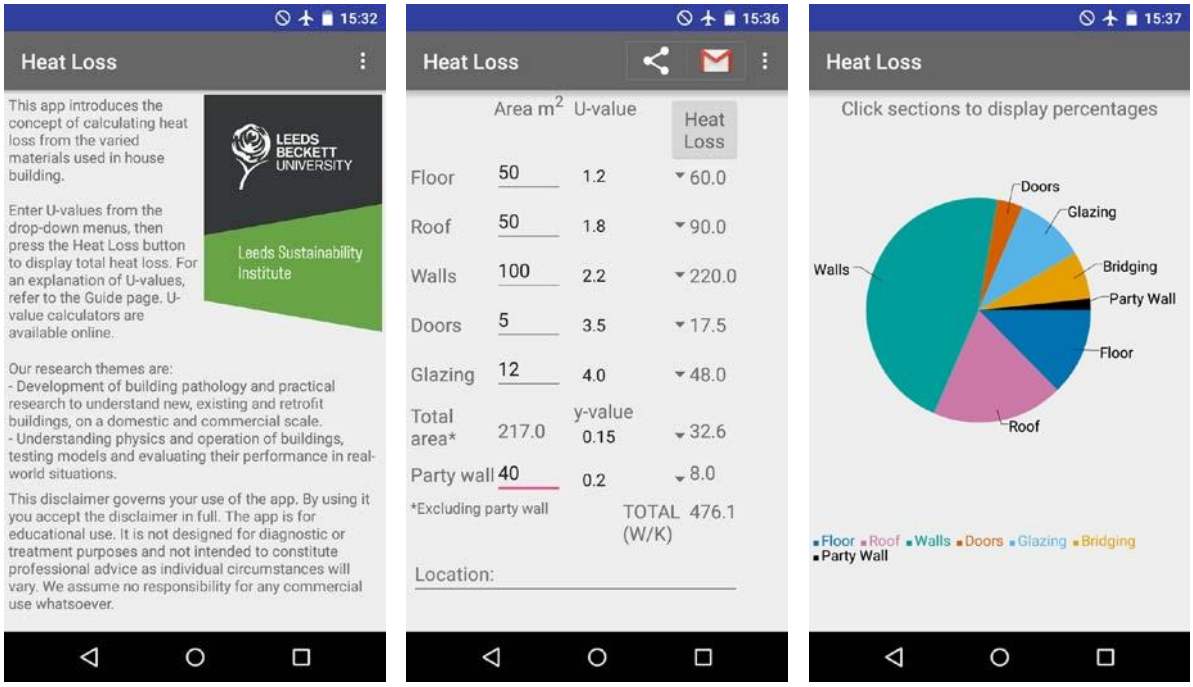


Figure 7. Screenshots of the app after the amendments were made.

CONCLUSION

From our experience, the ideal scenario for introducing e-learning tools to students is through a classroom group session, as suggested in Ellis et al. (2006) and further evidenced by our findings in this research paper. Group work seems much more effective than online surveys for gaining useful feedback. As can be seen from the types of responses to the two methods in the Methodology section, online surveys tend to produce one-sentence responses. Students are more forthcoming during group work; its conversational nature brings up issues and debate that individual working may not. Hsu and Ching (2013) have shown the interest in educators and students developing mobile apps to enrich learning environments. Although this app was not developed by students, asking students to test it can help in its iterative fine-tuning.

Thorough testing prior to release is vital to the success of an app. Alpha testing (generally within the publishers' organisation) and beta testing (external to the organisation) should be performed before releasing the app. Criticisms and suggestions for improvements are also likely to be made after the app has been released. Student group work produced several ideas for improvements that were subsequently included in the app. Group work prior to release of the app can be a useful testing method for the developer.

Creating e-learning resources as apps for mobile devices presents difficulties for the developer. The two dominant operating systems in the market, Android and iOS, require apps to be written in different development software (Android Studio and iOS SDK respectively) and in different computer languages (Java and XCode respectively). Writing an app for both operating systems entails duplication of significant amounts of development work. It may be advisable for the developer to take the approach of asking the student group which devices they are using before embarking upon writing the app. In the authors' case, this may have led us to decide to write the app for iOS. However, this may have reduced its potential use outside of the University, given the figures for worldwide smart phone sales. Student reports of difficulties when trying to run the app on Bluestacks make that an impractical solution. HTML5 app development may present a solution to this issue in the future.

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TOWARDS THE DEVELOPMENT OF A FRAMEWORK FOR INCORPORATING SUSTAINABILITY EDUCATION IN THE BUILT ENVIRONMENT CURRICULUM

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Abstract

Many proponents believe that there is a linkage between the green agenda and built environment (BE) education. It is increasingly recognised that the BE education curriculum should incorporate sustainability and produce graduates that are confident of taking care of the environment without damaging it for future users. Achieving education for sustainable development within the quantity surveying curriculum and more generally in BE curriculum will require an exploration of the general definition of sustainable development and its three spheres; economic, environmental, and social. In addition, one must acquire knowledge of regulatory and technological issues that encompass both the parts and the whole in dynamic interaction. Clearly, universities operating in the BE field have a vital role in shaping the future pattern of practice and policy in relation to the sustainability agenda. So, it is vital to map the curriculum towards sustainability. This research has been developed in response to the growing need of education for sustainable development. Whilst the study identifies the quality and quantity of sustainability related materials within existing BE curriculum, future research is needed to develop a modular framework for further integration of sustainability education in BE programmes. This framework could serve as an evaluation and a benchmarking tool for those who engage in developing the content of BE degree programmes.

INTRODUCTION

The sustainability revolution, which occurred over three decades ago, has culminated in the realisation that the world runs the risk of unsurmountable challenges if it does not embrace sustainability (cf. Miller *et al*., 2014). From the perspectives of proponents, the concept, which hinges on the future of humankind and the relationship between society and its natural environment, offers economic, socio-cultural and ecological benefits (Crofts, 1999). These benefits, as argued by proponents, manifest in several indicators. These include: poverty eradication or reduction; gender equality; economic growth with creation of jobs and promotion of strong economies; better standard of education and healthcare particularly in relation to water quality and better sanitation; and resilience in terms of the effects of climate change among other indicators (Olsen and Fenhann, 2008; Prüss-Üstün, 2008; David *et al*., 2013). Accordingly, sustainability has become very popular and engaged the attention of policy makers and implementers, as well as industry players across all disciplines. Indeed, Bell and Morse (2008) note that sustainability has become central to development discourse in a manner that only few development initiatives or research proposals are able to secure

sponsorship or funding without the words “sustainability” or “sustainable” appearing in such proposals to funding agencies.

Although various disciplines have adopted and are adopting the principles of sustainability, the attention on sustainability and its application within the built environment continue to intensify. This is because of the crucial role the built environment plays in the destruction of natural, human and social capital (Holdsworth & Sandri, 2014). For example, it is estimated that buildings and the building industry consume 32% of the world’s resources including between 40-50% of energy and up to 16% of the water used annually worldwide (IyerRaniga *et al*., 2010; Holdsworth & Sandri, 2014). Further, the building industry produces about 40% of waste that goes to landfill and accounts for 40% of air emissions (Holdsworth & Sandri, 2014). This implies that the intensification of the application of sustainability principles within the built environment is justified and there is a need for mechanisms for their implementation. At the heart of any strategy to implement or promote sustainability principles within the built environment is a well-crafted sustainable built environment education curriculum for stakeholders, such as built environment students and professionals (Iyer-Raniga *et al*., 2010). This is to equip graduates from higher education, professionals and other stakeholders to use and manage the built environment sustainably.

However, such a sustainable built environment education curriculum requires a suitable framework given sustainability education is unique, differing immensely from other, more conventional modes of education (Holdsworth & Sandri, 2014). This is compounded by the fact that knowledge obtained from sustainability science and related fields to support transitions to sustainability remains a critical theoretical and empirical question for basic and applied research (Miller *et al*., 2014). Although several studies (Iyer-Raniga *et al*., 2010; Iyer-Raniga and Andamon, 2012; Holdsworth & Sandri, 2014; Altomonte *et al*., 2014; Conte, 2016) have examined the link between sustainability and the built environment education in an attempt to prescribe a sustainable built environment education curriculum. The development of comprehensive framework for the incorporation of sustainability in the built environment education remains elusive.

Consequently, this study aims to contribute to the development of a comprehensive framework to incorporate sustainability into the built environment education curriculum. The concept of Sustainable Development within the Construction Industry is explored and literature relating to the importance and challenges of embedding sustainability in built environment education is explored before a series of four case studies are undertaken appraising existing RICS accredited QS degree programmes to appraise levels of sustainability inclusion within the curriculum. From this analysis, a modular framework for integration of sustainability education in built environment programmes is proposed.

SUSTAINABLE DEVELOPMENT AND THE CONSTRUCTION INDUSTRY

Sustainability and sustainable development (SD) are inextricably linked. Environmental, industrial and manmade disasters continue to trouble human existence. It is generally accepted that some natural disasters caused by forces of nature are inevitable. However, proponents in this field believe that we must do something about manmade and environmental hazards such as the threat of global warming caused by human action or inaction (Spence & Mulligan, 1995; Azapagic, Perdan & Shallcross, 2005; IPCC, 2014; Yilmaz & Bakis, 2015; Zaid, Jones & Holgate,

2017). Apart from being the morally acceptable thing to do, the current generation as the custodian of the built environment owe it to future generations to preserve and maintain the natural habitat. This was the main theme in the report of the World Commission on Environment and Development (Brundtland, 1987), and several global events thereafter have reinforced the idea of SD (Ekundayo *et al.*, 2011).

According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), global warming otherwise referred to as climate change is caused by the emission of greenhouse gases (GHGs) mainly carbon dioxide (IPCC, 2014). There are different aspects to sustainability (Son *et al*., 2011; Gan *et al*., 2015; Yilmaz & Bakis, 2015), but the fundamental principle is for all development activities to be both less resourceintensive and less environmentally damaging (Spence & Mulligan, 1995; Sev, 2009). The crucial elements often referred to as the triple bottom line of SD are society, environment and economy. While the topic of sustainability remains highly contested, it is evident that the earth finite resources must be managed effectively whilst at the same time reducing GHG emissions accumulating in the biosphere. This is necessary for the survival of the earth and its current and future occupants.

As mentioned by Spence and Mulligan (1995), the rapid depletion of the world's finite resources and the build-up of GHGs in the habitat leading to global threat of climate change implies that the construction industry has a vital role to play in achieving a sustainable future. Infrastructure and its associated developments are key to economic growth and global competitiveness. The construction industry and its extensive workforce help to build resilient infrastructures and sustainable (built) environments that we all rely on. This multibillion pound industry is however one of the largest exploiters of natural resources and a major producer of GHGs such as embodied and operational carbon. Buildings and infrastructures make use of raw materials produced from mineral and natural resources. The extraction, production, transportation and recycling or disposal of these raw materials, are energy intensive. In addition, the buildings lifecycle, from cradle to grave i.e. from construction to demolition, have negative impacts on the environment (Tan *et al*., 2011).

According to Yilmaz & Bakis (2015), buildings use 45% of world energy and 50% of water. In a similar study, Dixon (2010) highlights the environmental hazards caused by buildings such as 23% of air pollution, 50% of greenhouse gas production, 40% of water pollution and 40% of solid waste in cities. As well as buildings contributing to 50% of raw material consumption, the waste produced by the construction industry varies between 15 and 50% as reported by Sev (2009). Clearly, the construction industry is resource-intensive and a major polluter of both built and natural environments such that sustainability is now a key concept in development thinking at all levels. This led to the assertion by Sev (2009) that the significance of the construction industry in achieving economic growth, social progress and effective protection of both built and natural environments cannot be overstated.

IMPORTANCE AND CHALLENGES OF EMBEDDING SUSTAINABILITY IN BUILT ENVIRONMENT EDUCATION

The purpose of this section are twofold, that is, to review the importance and challenges of embedding SD in built environment (BE) education. The construction industry has a vital role to contribute to SD as the major energy, mineral and natural resources consumer.
Construction industry is responsible for the development of nations and buildings as well as their associated infrastructures have numerous economic, social and environmental impacts. According to Son *et al*. (2011) the construction sector has the greatest impact on national economies and the environment. Structures can last for several decades and in some cases centuries. However, sustainable construction is a notion that cannot materialise without a solid understanding and knowledge of sustainability concepts.

Whilst the construction industry generates many benefits to the built environment and society at large, the pressure of its activities on the natural habitat is alarming. Depletion of the biological and mineral resources many of which are non-renewable and deterioration of the physical environment such as loss of soil, forests and agricultural land, as well as increasing air pollution, global temperature and sea level rise are only a few examples. The ambitious targets set by the UK Government for all new domestic and commercial buildings to be zero carbon by 2016 and 2020 respectively is a step in the right direction to curb the irreversible damage being done (Zaid *et al.*, 2017). Consequently, we cannot leave this to our industry thinkers and policy-makers alone to proffer solutions. Perhaps, we should focus more on BE stakeholders' particularly higher education institutions (HEIs) that educate construction industry professionals. The huge contribution that HEIs can make in achieving SD underlines the importance of embedding sustainability in BE education. Whilst
Government initiatives are having a positive impact, it is believed that HEIs are imperative in driving the sustainability agenda forward (Cotgrave & Kokkarinen, 2010; Sutrisna & Rowe, 2012; Fukukawa *et al*., 2013; Brennan & Cotgrave, 2014).

HEIs have been striving to incorporate sustainability into their BE curriculum in order to maintain the currency of their programmes. This is reinforced by the need for the education sector to ensure that construction graduates are fit for purpose and able to lead the design, construction and management of sustainable structures (Sutrisna & Rowe, 2012). BE professionals make decisions and engage in activities that can lead to physical alteration of the natural environment. This has led to the surge in interest in sustainability and calls for BE schools to educate economically aware, socially responsible and environmentally conscious graduates. Although this has been a topic of discussion for much longer, for example the UN declaration for the decade of education for sustainable development (ESD) 2005 to 2014 (UN, 2002), the development of a framework to embed sustainability into BE curriculum is long overdue.

Despite the growing importance of ESD in HEIs around the world, its implementation in the construction industry and BE sector remains a challenge (Brennan & Cotgrave, 2014). In a study carried out by Fukukawa *et al*. (2013), barriers to the development of an SD curriculum for degree programmes were identified. These include time constraints on the part of teaching staff along with their perceived lack of expertise about SD, the need for a coherent strategy at

the school level, attitudes towards ESD and lack of university initiatives of this kind. Earlier, Cotgrave & Kokkarinen (2010) classified the barriers into organisation and funding of UK universities, academic indifference and approach to teaching and assessment, and lack of communication between industry and academia. While the barriers are being addressed by HEIs that promote ESD, there is need for a framework to enhance the creation, implementation and delivery of ESD programmes in BE schools. Cotgrave & Kokkarinen (2010) describe this as a sustainability literate construction curriculum. The proposed framework will address the perceived lack of action from HEIs and will ensure that sustainability literacy is fully realised in practice.

PREVIOUS RESEARCH ON SUSTAINABILITY EDUCATION

Sustainability is often perceived as a political propaganda inspired by environmental consciousness and driven by socio-economic factors. Yet, the importance of ESD in the construction curriculum is widely accepted. Sustainable development, green supply chain management and sustainable construction are just a few of the lexicons bandied around in the construction industry and other sectors as a means to an end, a way to achieve sustainability. As such, different studies over the years have examined the nomenclature of sustainability, but limited research exist on how this concept can be integrated into BE curriculum (Cotgrave & Kokkarinen, 2010; Sutrisna & Rowe, 2012; Fukukawa *et al*., 2013).

A recent study by Tan *et al*. (2017) investigated the extent in which sustainable development is embedded in the construction related curriculum based on the perception of quantity surveying students. The findings from this study and a review of extant literature revealed that students have basic/limited knowledge of sustainability despite the high importance placed on sustainability education from different directions. This supports findings from previous studies, which suggest that the level of inclusion of sustainability in the curricula appears to be low (Azapagie *et al*., 2005; Cotgrave & Alkhaddar, 2006; Perera & Pearson, 2011; Ekundayo *et al*., 2011). In the light of the above, it was suggested that there is the need for a framework for embedding sustainability education in the curriculum.

Fukukawa *et al*. (2013) examines the implementation of ESD within a business school through a case study approach. Similarly, Ekundayo *et al*. (2011) attempted to map sustainability education to construction related curricula using a case study of quantity surveying degree programme. Consequently, this led to the development of a sustainability framework relevant to quantity surveying degree programme. The framework groups the sustainability-related knowledge areas relevant to QS education into six main categories (such as background knowledge and concept, policies and regulations, environmental issues, social issues, economic issues, technology and innovation) with several subcategories. It is on this basis that this study becomes imperative with a view to develop a framework for embedding sustainability education into BE curriculum.

Sustainability is a global issue and human building activity has huge ramifications for current and future generations. A truly sustainable project, which is economically viable, socially acceptable and environmentally friendly, requires a concerted effort. Construction

professionals such as Architects, Quantity Surveyors and Project Managers, educated in BE schools, are tasked with the responsibilities of designing, costing, constructing and managing these structures. BE professionals thus have an important role to play in creating a healthy built environment, juxtaposed within the natural habitat, which are affordable and accessible. To this end, this research would be of great value and would eventually lead to the development of a future paradigm for BE curriculum design.

RESEARCH METHODOLOGY

Previous research established that there is indeed a discourse and a gap on how the sustainability issues are taught in built environment programmes in the UK. The current research sought to develop a framework that satisfies the aspirations of the various stakeholders (i.e. students, universities, professional bodies, industry, etc.). The main research instrument used to achieve this include case studies. Detailed case studies of four universities, which the authors have identified as A, B, C & D were used to generate a sustainability mapping for the study.

The case studies include examination of four RICS accredited QS degree programmes. The curricula of these programmes (module specifications, module handbooks, programme specifications) were analysed to establish the common thread in all the programmes in the four universities. The ensuing outcome of the analysis was then verified for accuracy and consistency with programme directors and module tutors responsible for delivery of these programmes and with some recommended industry liaison board members of the various universities involved.

Case study uses a variety of data collection techniques, such as questionnaires, observations, interviews and published documentary information etc. (Yin, 1994). The advantage of using this method of data collection is that it takes into account the numerous literatures available by narrowing down the scope in order to seek understanding of a particular phenomenon, which is the aim of this study. The case study will be analysed from quantitative (i.e. descriptive analysis) and theoretical point of view to create the sustainability mapping. The latter involves searching-out of underlying themes in the materials being analysed and making critical evaluation of the extracted themes (Bryman, 2008).

Case Studies

The four case studies selected were leading QS honours degree programmes in the UK all accredited by the RICS. The QS undergraduate programme is either studied as BSc (Hons) Full Time for 3 years full-time or 4 years sandwich. In Year 1, (otherwise known as Level 4), studies focus on the principles of knowledge on which quantity surveying is based including undertaking a UK-based residential field study visit. Year 2 (or Level 5) concentrates on the role of the Quantity Surveyor in practice and prepares students for work in the optional placement year. Students are strongly encouraged to undertake a placement year as it gives them the opportunity to put into practice what they have learnt in the first 2 years of their study before progressing onto the final year. In Final Year (otherwise referred to as Level 6), the broader role of the Quantity Surveyor is investigated whilst further developing relevant academic skills and undertaking an optional European-based residential study visit.

These four universities are the major providers of QS and construction related programmes and training in the UK, therefore, their programmes have to be sound, up to date and at the fore front of knowledge. This is critical if they are to maintain their absolute relevance well into the future and to keep attracting applicants from within the UK and worldwide. The adequate inclusion of sustainability education into their curriculum is of paramount importance to produce graduates confident of taking care of the built and natural environments. It is therefore necessary to examine the extent of coverage of sustainability within their QS curriculum, which is the focus of this study.

Sustainability Mapping

Ekundayo *et al*. (2011) developed a sustainability framework (see figure 1), which identifies the knowledge areas relevant to the QS degree programme and the profession. The framework, developed based on current and future roles of the professional quantity surveyor as informed by the sustainability agenda, categorises the sustainability-related knowledge areas relevant to QS education into 6 main categories (high level categories) with several subcategories (low level categories). The curricula (module specifications, module handbooks, programme specifications) of the four universities were mapped against the sustainability framework to evaluate the extent of coverage of sustainability education in these QS degree programmes.

SUSTAINABILITY FRAMEWORK						
HIGH LEVEL CATEGORIES	CATEGORY A - BACKGROUND KNOWLEDGE AND CONCEPT	CATEGORY B - POLICIES AND REGULATIONS	CATEGORY C - ENVIRONMENTAL ISSUES	CATEGORY D - SOCIAL ISSUES	CATEGORY E - ECONOMIC ISSUES	CATEGORY F - TECHNOLOGY AND INNOVATION
LOW LEVEL CATEGORIES	Sustainable development overview and principles Climate change and global warming issues Impact of the construction industry on the environment Sustainable construction concept Role of QS in sustainable development	Changes to Building regulation, e.g. Part L (energy efficiency) and Part F (means of ventilation) Code for Sustainable Homes Energy Performance Certificate (EPC) The Kyoto protocol Relevant EU Directives such as the EU climate policy, EU ETS, etc Climate Change Act Sustainable Construction Strategy Sustainable Procurement Action Plan	Protecting and enhancing the built and natural environments Environmental Impact Assessments (EIA) Environmental Management Systems: ISO 14001 Environmental Assessment Methods: BREEAM, LEED, Green Star Reducing energy consumption, that is, emitted and embodied Reducing greenhouse emission such as methane, carbon, nitrous oxide and refrigerant gases Carbon Agenda (Carbon footprinting, Zero Carbon, Retrofit) Waste reduction principles (recycling, reduction, reuse, effective design) Brownfield development Natural resources, renewable and non-renewable materials Water usage and Sustainable Transportation Plan	Corporate Social Responsibility (CSR) Ethical issues such as ethical sourcing of materials and labour, for instance Equity and social justice Community development and social inclusion Health & safety Employment, training and education Social assessment methods (e.g. Design Quality Indicators, KPIs and benchmarking, etc) Cost Benefit Analysis (i.e. impact of human factors on the community)	Cost planning and management Value management or engineering (cost of alternative materials and designs) Sustainable procurement strategies Feasibility studies Whole-life appraisal/ Life cycle costing Financial incentives (such as subsidies, climate change level, aggregate tax, carbon credit, Brownfield land tax, etc)	Renewable energy technologies (Photovoltaic, Wind Turbine, Geothermal, Biomass, etc) Green Building Materials Rain water harvesting and Grey water collection systems Professional and management software packages such as BIM, etc Modern methods of construction: offsite production, use of precast material, lean construction, etc Passive design methods such as day lighting, intelligent facades, carbon storage and offsetting, etc Supply chain management Effective information control and management (using e-business)

Figure 1. Sustainability framework relevant to QS degree programme (Ekundayo *et al*., 2011)

RESEARCH RESULTS

The sustainability mapping of QS degree programmes, shown in figure 2, reflects the overall coverage of depth and breadth of coverage of the sustainability issues within the four case studies. The outcomes of the mapping illustrate how the sustainability issues are embedded in

the modules, specifications and the handbooks of the four case studies. As can be seen from figure 2, all the pre-determined sustainability issues are present in all four universities, however, how these attributes have been embedded are inconsistent across the four case studies, and more alarmingly attainment often achieved in isolation, for instance through one specific module. Rather than through a more considered and holistic curriculum design that ensures sustainability and sustainable development are robustly addressed in contexts relevant to the profession.

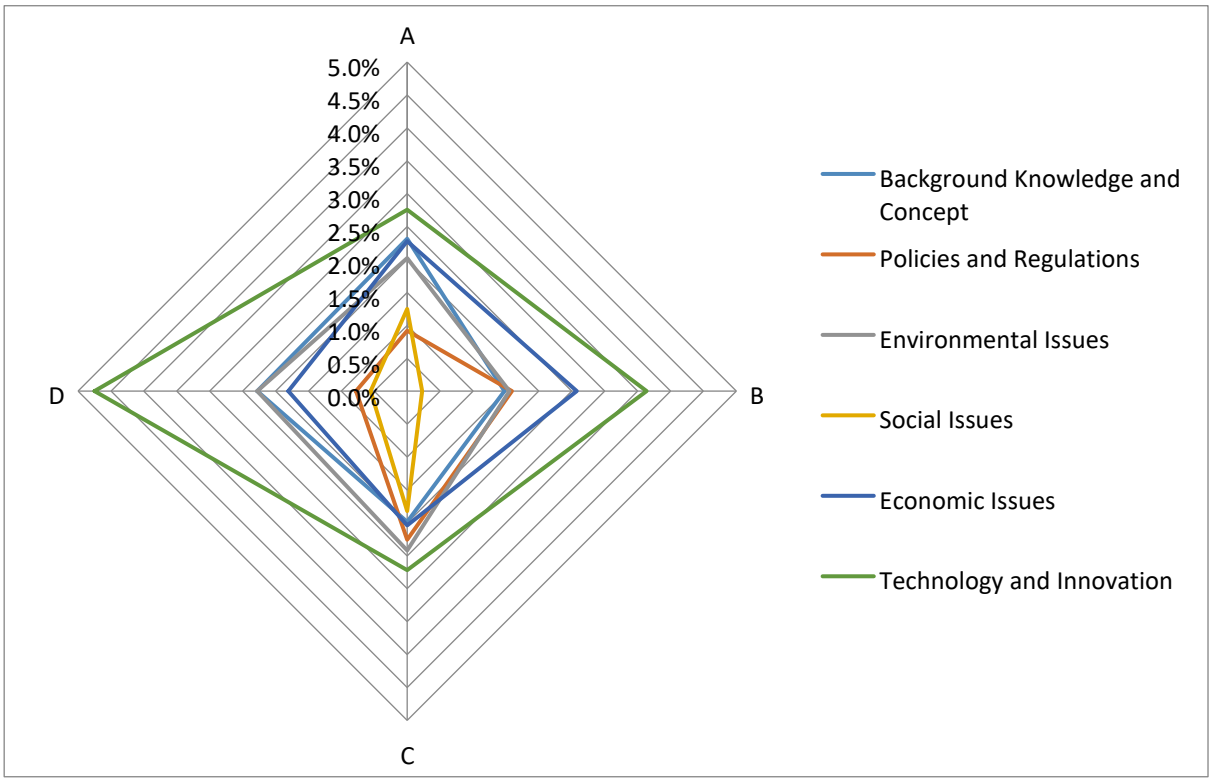

Figure 2. Sustainability mapping (high level categories) of QS degree programmes

DISCUSSION AND CONCLUSION

The quantitative results illustrate that the curriculum, at least in these four institutions, emphasises technological and innovation aspects rather than broader sustainable development issues and more than any other categories in the framework. While this is interesting, it is not so surprising as subjects such as renewable energy technology, BIM, green supply chain management and passive design methods among other things have become very popular and central to the sustainability discourse. This finding is interesting because more than often, sustainability-related literature (such as Spence & Mulligan, 1995; Azapagic *et al*., 2005; IPCC, 2014; Yilmaz & Bakis, 2015; Zaid *et al.*, 2017) accord greater emphasis to the background knowledge and concept subject areas as revealed in the literature.

As the mapping was done against QS degree programmes, it would also have been expected that economic issues such as cost planning, value management, sustainable procurement

strategies, and whole-life appraisal be covered in the curriculum at a higher level than any other sustainability issues in the framework. Nevertheless, this more or less emphasises the role of technology and innovation in sustainability implementation. Also, technology is now often use to enhance the role of a quantity surveyor. The somewhat disturbing part of the findings however is that economic issues are covered at a relatively low level in some institutions, and this cannot be right. Further investigation is thus required in this regard.

The coverage of environmental issues and policies and regulations in the curriculum is plausible in the light of previous work and perspectives of proponents in the field such as Bell and Morse, 2008; Olsen and Fenhann, 2008; PrÜss-ÜstÜn, 2008 and David *et al*., 2013.
However, the very low coverage and emphasis on social issues is not so surprising.

Literature that discuss issues such as corporate social responsibility, ethical issues, equity and social justice, cost benefit analysis and social assessment methods as an important part in the sustainability discourse are rare. Consequently, this is reflected in the very low (and in some cases non-existence) level of social issues in the QS curriculum.

Generally, the above findings support results from previous studies like Perera & Pearson (2011) and Tan *et al*. (2017). Sustainability may be evident across only 0.5-4.5% of the curricula of Quantity Surveying programmes, at least in these four institutions, and incorporated at a basic level only. This is in spite of the need and relentless call for a framework for embedding sustainability education in the curriculum as the literature review suggested (Azapagie *et al*., 2005; Cotgrave & Alkhaddar, 2006; Ekundayo *et al*., 2011).

Professional institutions are increasingly placing more emphasis on broader issues of sustainable development, and there have been explicit requirements of mapping BE curriculum against addressing sustainable development issues. As such sustainable development should be seen in such neat categories of competence areas as identified in the sustainability framework. Understanding and addressing sustainable development is, however, a good problem. Thus, this calls for multi-disciplinary and often innovative ways of teaching and learning the 'subject'. There needs to be some acknowledgement of this, and also progress made especially in encouraging multidisciplinary approaches to education for sustainable development. This research agrees with previous work (e.g. Ekundayo *et al*., 2011) that a concerted effort across the disciplines is needed in order to integrate sustainability issues into BE programmes. Including the views and input from other stakeholders such as students, professional bodies and industry practitioners in this regard is also of paramount importance.

Findings from the literature review and relevant work previously discussed, as well as this study, indicate that there are challenges to embedding sustainability in BE education. This study is part of a larger research within the education for sustainable development, which aims at diffusing sustainability into the curricula of BE programmes in UK universities. While this research focussed mainly on mapping the inclusion of sustainability within the quantity surveying curriculum, it is evident further investigation is now required to appraise the inclusion of sustainability within other BE degree programmes. Furthermore, whilst the study identifies the breadth and depth of sustainability-related materials within existing curriculum, future research is needed to develop a modular framework for further integration of sustainability

education in BE programmes. The framework could serve as an evaluation and a benchmarking tool for those who engage in developing the content of BE degree programmes, policy makers and implementers, as well as industry players across all disciplines.

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CHANGE COMMUNICATIONS: THE KEY TO EMBRACING AND IMPLEMENTING CURRICULUM CHANGE

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Keywords: Change management, Education, Communication strategies, Stakeholder empowerment and involvement.

Abstract

This paper investigates organisational change management in a curriculum change project at an Australian higher education institution and, more specifically, analyses the human factors in this process: communication strategies, empowerment and involvement, and overall approach to change management. As communication is the life blood of an organisation and the oxygen of change within any organisation, this paper emphasises communications strategies in order to engage and inform the relevant stakeholders in the change project. The study involves a specific case at the University of Sydney Medical School, where a change sizing survey was implemented. The findings reveal that in order for the change to be effective, stakeholders require involvement, empowerment and clear communications. This papers ultimate goal is to the goal to successfully implement change – an objective of which is stakeholder buy-in.

INTRODUCTION

Founded in 1850 by an Act of the legislature of New South Wales, the University of Sydney is the oldest university in Australasia and the university has a global reputation for providing quality education. The Sydney Medical School at University of Sydney formally came into being on 13 June 1856. This case study focuses on the Sydney Medical Program (SMP), which is a graduate entry medicine course (MD) with an annual intake of approximately 300 students, made up of 73–76% domestic and 24–27% international enrolments. The medical program is delivered at nine clinical schools: seven in metropolitan Sydney plus the School of Rural Health in Dubbo and Orange and the University Departments of Rural Health in Broken Hill and Lismore. The medical degree offered by the University of Sydney has undergone several changes over the last two decades. In line with the University of Sydney's strategic plan for education 2016–2020, the SMP is now planning a revised curriculum to be implemented in 2020, with the new iteration due to take enrolments in 2020. It will remain a graduate entry MD program but there will be significant changes in the curriculum including the structure and method of teaching delivery and assessments.

According to Calvin Coolidge, "Changing a college curriculum is like moving a graveyard—you never know how many friends the dead have until you try to move them" (1985). As noted by Coolidge and other researchers (Verhulst & Lambrechts, 2015; Ngirwa et al, 2014; Mumford

et al, 2000), changing a university curriculum can be a difficult process, as most people do not like change. This is why in this approach on this project was unique and has incorporated change management. The goal with this project was to ensure that as many stakeholders as possible took part in the MD curriculum update. This was done by establishing working parties, committees and workshops, running town hall meetings, having a Yammer (an enterprise social networking platform used for private communication within organisations) page for the new MD curriculum, having a specific new MD project staff newsletter, holding regular meetings with all stakeholders (sometimes one on one, other times meeting as a whole team) and conducting regular clinical school visits. As part of our stockholder involvement, we conducted a change sizing survey in order to examine whether the changes were being embraced and implemented by the both academic and professional staff and whether clear and ongoing communication, stakeholder involvement and empowerment are the key to making this change, smooth, efficient, accepted and implemented. The overall goal of the change management strategy is to have all stakeholders fully brought into the new MD curriculum program before the 2020 launch of the new MD curriculum, so that they are ready, willing and able to adapt to the new environment.

This paper particularly focuses on how the project management team engaged and brought stakeholders into the new MD curriculum project and how we approached change communications. The paper also investigates participants' views on change related issues, for example whether there is a need to change, ways to improve the change and the stakeholders' willingness to be involved in the project.

Background

Change is an ever-present feature of organisational life, both at an operational and strategic level (Burnes, 2004; Balogun & Hope Hailey, 2004; Burnes, 2004; Carnall, 2003; Kotter, 1996; Luecke, 2003; Moran & Brightman, 2001; Okumus & Hemmington, 1998; Paton & McCalman, 2000; Senior, 2002). Systemic change, which occurs when transitioning educational curriculum, is often a challenge to all concerned and, in some instances, may even create a negative, divisive environment (Beyer & Liston, 1996) and without acceptance and buy-in by all major constituencies, long-lasting systemic change cannot occur. MacDonald (1975) suggests that "in many ways, all curriculum design and development is political in nature." Other researchers have similarly acknowledged that curriculum development and design initiatives will sustain many challenges, as curriculum change is political in nature and can be influenced by political factors (Nousiainen et al., 2017; Gornitzka et al, 2005). Change management has been defined as "the process of continually renewing an organization's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers" (Moran & Brightman, 2001: 111).

In order to achieve the desired change, efficient and effective communications is vital (Kotter 1996; Moran et al., 2001). Internal communication on change is identified as a human factor that influences change process in higher education (Verhulst & Lambrechts, 2015).

Historically, organisational communication scholars have been fascinated by the connection between communication and change. The work done by communication scholars regarding issues of participation in decision-making (Seibold & Shea, 2001), emotion (Zorn, 2002), identity (Chreim, 2002) and vision (Fairhurst, 1993, 2008; Russ, 2008) have identified some of the ways communication may impact the design of change processes as well as their adoption and acceptance. Research has focused on developing change strategies for managing multiple stakeholders' needs, concerns and participation during the implementation of planned change initiatives (Lewis, 2007; Lewis & Seibold, 2009). Kotter (1996) highlights that communicating to employees the need for change and how it can be achieved is critical to the successful management of change. According to many other researchers (Keesing-Styles et al, 2014; Ngirwa et al, 2014; Peters and Waterman, 1982; Porter, 1985; Kanter, 1983; Heller, 1998; Clarke & Clegg, 1998; Peterson, 2000; Kitchen & Daly, 2002), the determining factor in whether or not organisational change is achieved is employees and how they are engaged in the change process.

Communication is key to effective implementation of change programmes as it is used as a tool for announcing, explaining and preparing people for change, including the anticipated positive and negative effects (Verhulst & Lambrechts, 2015; Spike & Lesser,1995). Lippitt (1997) argues that internal communication can increase understanding of the commitment to change as well as reducing confusion and resistance to it. Grunig (1992) extends this idea further, stating that "internal communication...is the catalyst if not the key to organisational excellence and effectiveness."

In organisational change management literature, there is a strong focus placed on human factors, such as the human commitment to what needs to be changed, which are indicated as success factors (Struckman & Yammarino, 2003). Other human factors are the empowerment and the involvement of employees, commitment to what needs to get implemented, inductive learning, the adaptation of the organisational culture and clear communication (Verhulst & Lambrechts, 2015; Barge, Lee, Maddux, Nabring and Townsend, 2008).

As stated by the literature above, clear communication and strong support among all relevant stakeholders involved in the change process is necessary to ensure the effectual implementation of a new curriculum.

RESEARCH METHODS

Change in an organisation interacts strongly with the transformation processes that affect the sectors and environments with which it has important well-consolidated or potential links. There is widespread conviction that case studies are useful when studying change (Johnson-Cramer, Cross & Yan, 2003; Muratbekova-Touron, 2005; Van de Ven & Poole, 2005). Therefore, this paper uses a case study approach to focus on the University of Sydney's new MD curriculum review project. As stated earlier, it can be difficult to understand whether an institution is ready to accept change. Consequently, as part of the new MD curriculum renewal project, we conducted a change sizing and readiness survey in order to define approaches for the required change and to set goals and strategies to achieve the necessary changes. This

type of change sizing survey has been successful used at the Universities of British Columbia, Toronto and Washington to assist them with their medical school curriculum renewal initiatives (AMBiT Consulting Inc., 2017). This research uses a change sizing was specifically designed for our needs and it was run in December 2016 for the group made up of academic and senior staff and in March 2017 for the group made up of professional and clinical school staff.

The change sizing and readiness survey developed was based on the ADKAR (awareness, desire, knowledge, ability and reinforcement) model, which is a set of key concepts of change management. A change sizing survey can be useful for helping change leaders and stakeholders understand the magnitude of change. In this case, it helped us to identify what was necessary to ensure the change was accepted, embraced and then implemented.

The ADKAR model works by assessing individuals and organisations on five building blocks in consecutive order to measure their readiness to deliver successful change (Figure 1). By rating each phase of change "element" with a score between 1 (the lowest) and 5 (the highest), an ADKAR "profile" is created. The first element to score three or less is defined as a "barrier point."

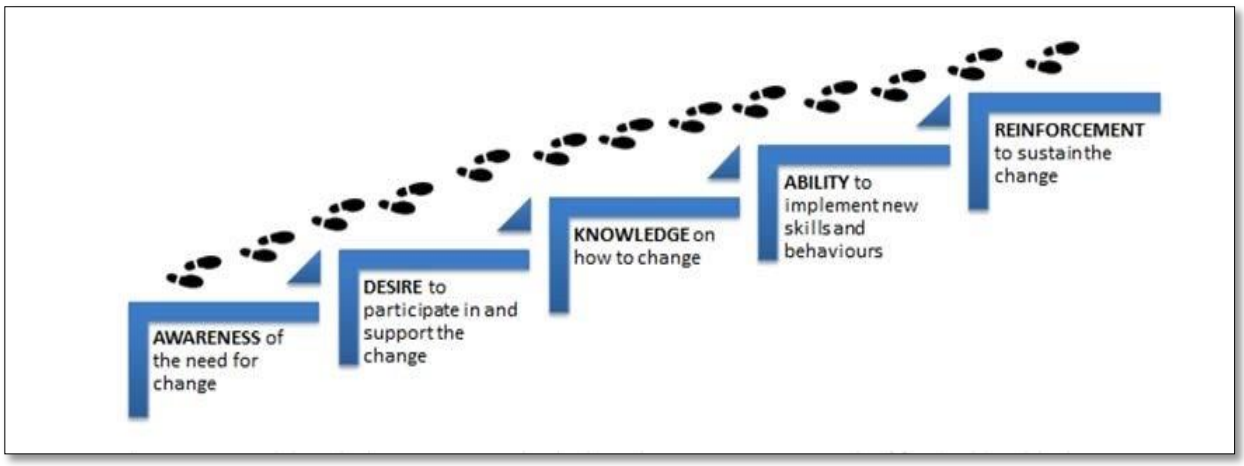

Figure 1: Key processes and five building blocks of the ADKAR model (Lad, 2014)

The survey participants were asked 17 multiple-choice questions and three open-ended questions. The survey was developed using LimeSurvey, which is a web server-based software that enables users using a web interface to develop and publish on-line surveys, collect responses, create statistics and export the resulting data to other applications. For the multiplechoice questions, participants were given a Likert scale spectrum (strongly disagree; disagree; neither agree nor disagree; agree or strongly agree) to choose from.

We predicted that the two groups, academic and professional staff, would have different concerns and needs. Since many of our senior staff are part of the project committees and working parties, we consulted and communicated with them heavily. It was therefore logical to ask our senior academic staff to participate and complete the survey conducted in December 2016. The project manager and project officer visited all metropolitan and rural clinical schools and consulted with professional staff before the professional staff were asked to complete the

survey in March 2017. The researchers contacted 52 senior academic staff (i.e. heads of schools, block chairs and professors) by sending the LimeSurvey via email. 34 (65%) participants completed the change sizing survey.

The professional staff and clinical school staff were also asked to complete the change sizing survey. 85 professional staff members were contacted using the same method as for senior academics and 44 (45%) competed the survey.

RESULTS

Survey participants were asked if they believed that there is a need to change the current MD curriculum.

- Academic staff: 85% of the survey participants stated that they believed there is a need for the renewal of the current MD curriculum.
- Professional staff: Just over 70% of the survey participants stated that they believed that there is a need for the renewal of the current MD curriculum.
- In the open-ended questions, we asked the both categories of survey participants (academic and professional staff) to provide us with feedback on how the change project can be improved.
- Most (88%) of the participants said that clear and timely communication was necessary.
- Just over 75% said that they would like to be involved in the project and 78% said that they would like to be consulted.
- This survey findings are also reinforced by several scholars (Adams, 2003; Kegan & Lahey, 2001; Lewis et al., 2006; Verhulst & Lambrechts, 2015) who studied staff empowerment, involvement and communication during a change project. This survey results highlighted staff's need for empowerment, involvement and the need for frequent, constant and clear communication during a change project.
- Additionally, the majority (89%) of the participants reported that this survey was the first time that they had been consulted and asked for feedback.

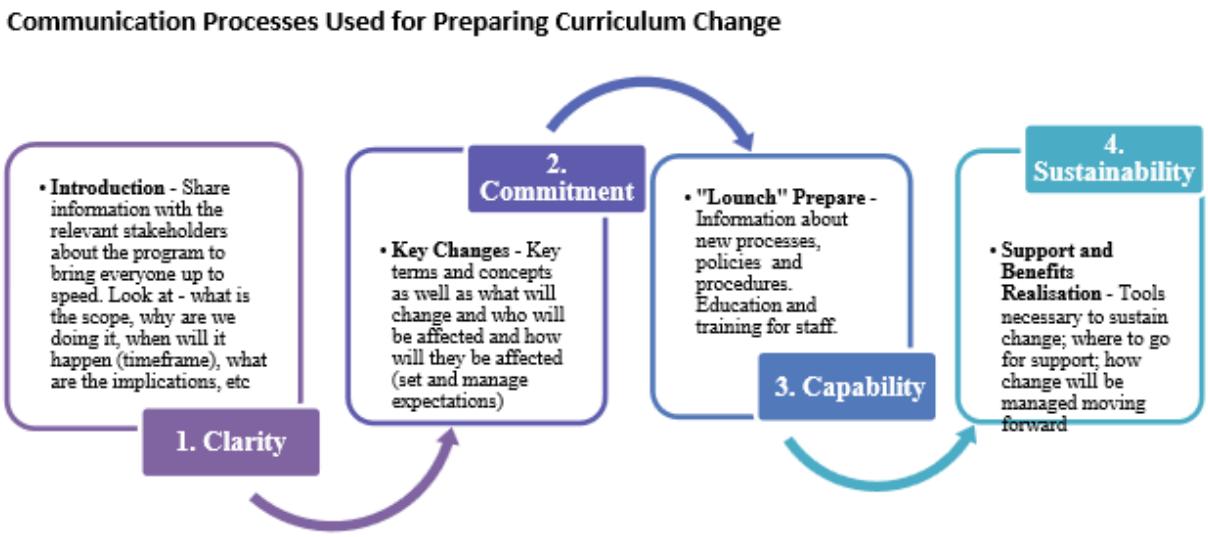

Figure 2: Elements and process model used for project communication in the MD curriculum change, adapted from Sustaining Change (2017)

As highlighted in Figure 2, the aim of all project communications is to keep everyone on board and supporting the project schedule as the organisation works towards the end goal. Hiatt and Creasey (2003) confirm the importance of engagement, especially within the change team. Kotter (1995) states that the more people get involved, the better the outcome of the change will be, under the condition that the actions performed by the people fit within the broad parameters of the overall vision on the change.

It was clear from the onset that we needed to identify the project's communication objectives to facilitate change. As the first step to do this, we developed a communication plan. A communication plan is a document that acts as a guide for the direction of the project. This plan should be updated regularly and it works as both a project management tool and a communication directive. Possibly the most important function of the plan is that it aligns all of the stakeholders involved in the project, thereby minimising the chances of going down minimising wasted time and effort.

Clear communication and strong support among all stakeholders involved in the change process is necessary to ensure an effective transition. Figure 3 highlights the steps that were taken to define change needs and better understand what communication methods would be necessary to ensure clear and timely communications.

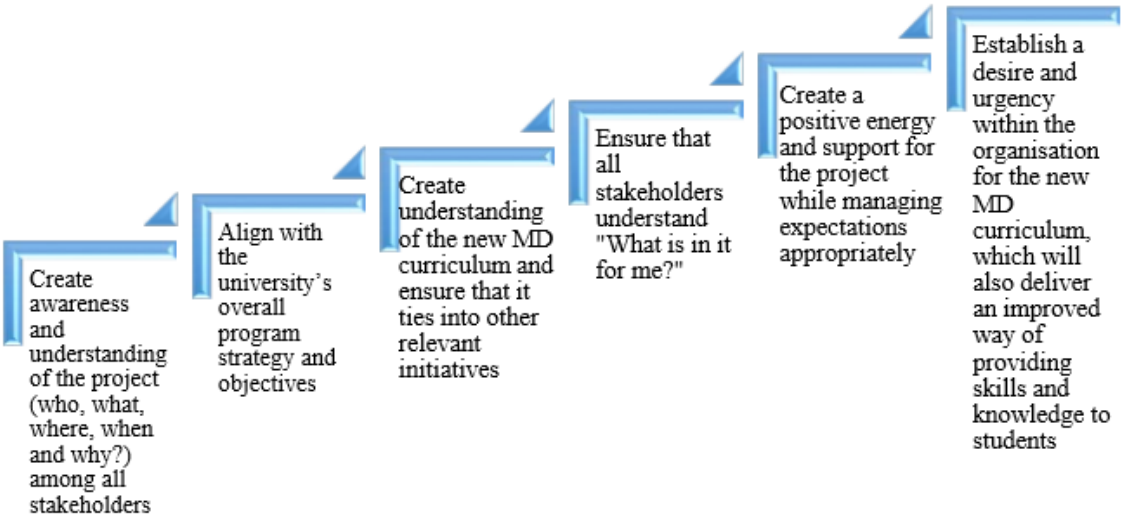

Figure 3: The steps to define change needs and better understand what communication methods would be necessary

In order to for the communication to be effective, the following items were taken into account:

- Stakeholder communication requirements
- Information to be communicated
- Reasons, time frame and frequency of distributing the communication
- Methods and mediums for sharing the information
- Person(s) responsible for communicating the information
- Person(s) responsible for authorising release of confidential information • Person or group that will receive that information

Communication Strategy Developed for Implementing Curriculum Change

Once there was a deep understanding of what changes were necessary and that communications, stakeholder involvement and empowerment were the key to the success of the required change, we developed a communications strategy. This had four key elements.

a) Communicate via manager/supervisor as well as directly with the clinical schools and university staff

- Communication has the best chance of changing behaviour if it comes from the most trusted source; for example, an employee's immediate supervisor may be the person most trusted to disseminate information.
- Some supervisors are better at communication than others and some may not pass on the information to their staff, which means that communication is lost. Consequently, we cannot rely on communication trickling down through to relevant clinical schools and university staff. Instead, changes should be communicated directly to clinical school and university staff (as well as their managers).

b) Target influential people – have them become change champions

- Ensure the buy-in of key people in each clinical school so that they can help us lead change.
- Develop a summary document on the overall changes and implications of the new MD curriculum, which our change champions can use when talking to their staff

c) Establish two-way communication so employees know that their involvement is important and valued; this will create buy-in and support

- Solicit employee input whenever feasible. This can be done through various working parties and committees.
- Establish a way for all employees to be able to submit questions and provide the project team with feedback. This could be done via meetings and working groups, question and answer sessions, town hall meetings and lunch and learn events.

d) Meet the information needs of the various stakeholders

- Strategically build awareness acceptance of the new MD curriculum.
- Satisfy people's curiosity so they know what is in it for them
- Ensure that people's expectations are managed.

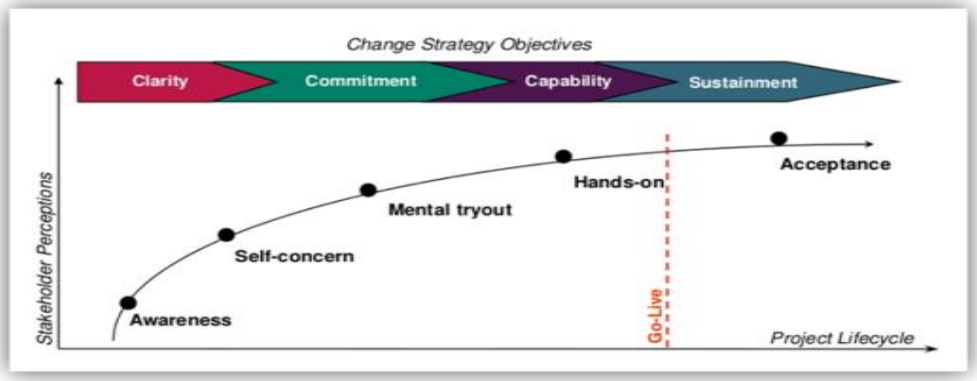

Figure 4: Change strategy objectives (Steblay, 2014)

Effective change communication is resource intensive and is characterised by a high degree of interaction and face-to face meetings. The greater the change, the greater the need for "in person" communication (Steblay, 2014). Some effective mediums that should be used as much as possible to ensure effective change communication are one-to-one meetings, department and staff meetings, workshops and specialised committee meetings. The following mediums should only be used to create general awareness: emails, intranet, staff newsletters and executive briefings (Steblay, 2014). In addition to communicating our message, we also need to

foster engagement with our stakeholders by engaging them in dynamic interactions. The types of communication and engagement activities are presented in Table 1.

Table 1: Communication and Engagement Activities in Change Project

Communication activities	Engagement activities
Emails	Committees and working parties
Newsletters	Question and answer sessions
Videos	Town hall meetings
Posters and flyers	Learn and lunch sessions
Presentation material (for e.g., PowerPoint slides and posters)	Interviews and focus groups
Internal postings – e.g., Yammer	Informal hallway conversations and unscheduled office drop-bys

CONCLUSION

This research has shown that some of the most important factors in achieving curriculum change is clear communication and the involvement and empowerment of staff. There is no doubt that if we do not consult widely with our stakeholders, if we did not get them involved via the working parties and committees and if we did not let them have a say, make decisions and listen to their feedback, this curricular change would simply not be possible.

The effort to initiate and sustain this new MD curriculum will be significant, despite the trials and tribulations that will undoubtedly occur. This change to the Sydney Medical School's curriculum will lead to developing compassionate, diverse and innovative lifelong learners who work in partnership with individuals and communities to improve health through clinical care, education and research.

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Procurement and Building Performance

AN EXAMINATION OF IRISH CONTRACTING FIRMS POLICIES ON SUSTAINABLE CONSTRUCTION PRACTICE

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Key Words: construction industry, organizational policies, sustainability and sustainable construction

ABSTRACT

Implementing sustainability policies is an indication of firms' disposition to collaborate closely with their supply chain. This study examines the organizational policies of the top 50 Irish construction-contracting firms on how they refer to the matter of sustainability. List of the top 50 contracting firms was obtained from the Construction Industry Federation (CIF) 2016 report, and the companies' websites were used to obtain their policies. Key sustainability issues were identified using the content analysis method. The summary of the results shows that out of the top 50 construction companies 14%(7) had a clearly stated policy on sustainability, 34% (17) had policies that were not clearly stated and 52% (26) did not have any policy stated on sustainability. The research further categorized and analysed the organizational policies of the firms based on the type of work undertaken and their annual turnover. It is indicative that a firm with a high turnover is likely to address sustainability in their company policies. Some of the issues the top firms stated in their policies on sustainability are gaining competitive advantage through responsible sourcing, engaging community and recycling of waste and other construction products. The results further revealed that the nature of work undertaken by a company is a possible motivator in promoting sustainability to enable a firm gain competitive advantage.

INTRODUCTION

The construction industry globally is being called upon to embrace innovative practices in the way they operate by having the consideration to the environment, its people, and resources. On the global scene, the United Nations Climate Conference (COP21) report (The Paris Agreement) article 10:5 emphasized that organisation and corporations will have to change and improve the way they do their business in order to achieve a long-term global response to climate change, promoting economic development, and sustainable development (United Nations Framework Convention on Climate Change 2015). Also, during the World Summit on Sustainable Development in 2002, world leaders agree to commit and support the sustainability agenda in their various countries by recognizing that sustainable development requires a long-term perspective and broad-based participation in policy formulation, decision-making, and implementation at all levels (WSSD 2002). This call has made government in various regions and countries to create laws, incentives,

regulations, and policies that will motivate businesses in the way they operate (Baker 2006). For example in the Republic of Ireland, the Department of Communications Climate Action and Environment reported that, in order for the Irish buildings to meet the strict European Union (EU) regulations by avoiding fines, and for their buildings to meet the Energy Performance of Buildings Directives (EPBD) the government had issued directives that:

1. All buildings built after 31 December 2020 must have high energy-saving standards and be powered to a large extent by renewable energy.
2. By the end of 2018, the public sector must own or rent only buildings with high energy-saving standards and promote the conversion of existing buildings to "nearly zero" standards (Department of Communications Climate Action and Environment 2012).

The Architectural, Engineering and Construction (AEC) sector globally has shown commitment to the adoption of sustainability principles through their construction process and practices. This is mostly shown in their organisational policies and mission statements where sustainability is positioned as a primary focus (Berry & McCarthy 2011; Meehan & Bryde 2011; Zuo et al. 2012). Organisations implementing sustainability policies is an indication of the firm's disposition to collaborate closely with their supply chain in meeting the sustainability goals of a project (Searcy 2017). In addition, (Zuo et al. 2012) noted that other approaches taking by construction companies in promoting the adoption of sustainability in their operations are through a statement of principles, sustainability reporting incorporated within a financial report, and a stand-alone sustainability reporting system.
Learning from the AEC sector in the United Kingdom, Berry & McCarthy (2011) reveal that large construction companies in the UK are addressing the issue of sustainability in their practice as follows:

- By starting to set their own standards as part of their value proposition
- Educating and challenging their clients and/or main suppliers to win long-term competitive advantage
- Working closely with their main suppliers to promote sustainability throughout the supply chains and deliver new sustainable solutions and
- Trying to provide the widest possible sustainability benefits when undertaking construction projects.

However, with best of effort and intention in achieving the primary aim of sustainability (Social, Economic and Environmental), various studies have shown that achieving the aim of sustainability in the AEC sector is challenging (Adetunji et al. 2003; Akotia et al. 2016; Essa & Fortune 2008). Similarly, Meehan & Bryde (2011), argue that even when an organisation has sustainability as a top priority in their organisational policies, realising the aim is still a challenging endeavour. Likewise, (Boyd & Schweber 2012) reveal that different firms address their sustainability policies and issues differently. While (Zuo et al. 2012) reveal that the main themes in the organisational policies of the top 50 global construction contracting firms are mostly centred around the environmental factors.

To further understand the practice of sustainability in the AEC sector, there is the need to closely study the organisational policies of construction firms in the different regions and countries on matters that refer to sustainability. This is necessary because construction sustainability practices differ according to organisations, regions and countries (Boyd & Schweber 2012; Van der Heijden & van Bueren 2013). Such study will contribute to knowledge by identifying the various peculiarities sustainability practices in the different regions and countries. (Berry & McCarthy 2011) strongly argue that organisational policies on sustainability are the fundamentals strategies that should be in place to provide the overall direction and to also guide in identifying the organisational priorities and goals as it relates to sustainability practice.
Therefore, this study examines the policy statement of the top 50 construction contracting firms in the Republic of Ireland in order to provide an insight into how contracting firms embed sustainability in their company policies.

LEVEL OF ADOPTION OF SUSTAINABLE CONSTRUCTION

Mainstreaming of sustainability is not the linear process as it is made to be seen but varies with the dominant organizational culture and history of each firm (Boyd & Schweber, 2012). Van der Heijden & van Bueren (2013) argue that sustainability attainment is a contextual matter influenced by local climate, culture, institutions and other factors. People from their perspective, decisions, and actions influence achieving organizational policies in terms of promoting sustainable construction as argued by Fellows (2006). Fellows (2006) further suggested that there is the need to move from the current practice of relativist approach in pursuing sustainability to an absolutism approach where it will require a collectivist approach through a change of culture that will view sustainability as a norm rather than an exception.

Furthermore, Yolles & Fink (2014) explained that there are variations on understanding what is meant by sustainability. They opine that sustainability is an ideological concept with different meanings for different people that reflect their different values and goals. What this suggests is that the level of understanding of what sustainability means can influence achieving the organizational goals and objectives as it relates to sustainability practice. In a study to assess the level of understanding of sustainability in the AEC sector, Adetunji et al. (2003) and Opoku & Ahmed (2013) revealed that practitioners have a better understanding of the environmental aspect of sustainability than the social and economic aspect. Similarly, Zuo et al (2012) observed that energy efficiency and conservation, greenhouse gas emission (GHG) reduction and integration of renewable energy resources into projects are among the common themes of the top global construction contractors' sustainability policies.

Besides the level of understanding of sustainability, another factor that enhances the adoption of sustainability is the capability of the people engage. Terouhid & Ries (2016) argue that workforce management and knowledge management are the key components of people capability that plays a vital role in the attainment of the sustainability performance of construction firms. In the same

way, Eilers et al. (2016), reveal that a positive impact can be experienced in the attainment of sustainability through employee satisfaction, project opportunities and market advantage on firms that embrace corporate sustainability culture in their practices. Although, (Phua 2018) argues that there is the need for further research to be undertaken to understand how firms implement their sustainability goals within their organisation to shape the behaviour and attitudes of employees. However, Opoku Cruickshank, & Ahmed (2015), support that good intra-organizational leadership can drive achieving the organization policies on promoting sustainable construction.

Furthermore, assessing and communicating the impact of embedding sustainability could be quite challenging, but the ability to communicate the various impact on sustainable investment to local societies, people, investors and other stakeholders can provide a competitive advantage (Räikkönen et al. 2016). Rodriguez-Melo & Mansouri (2011) explained that engaging and communicating sustainability goals to the stakeholders will help in increasing the manager's awareness, helping legislation to be effectively implemented and making sustainability highly appealing to clients. Also, the in the Republic of Ireland, the Environmental Protection Agency, admit that Green Public Procurement (GPP) is quite a complex process because apart from meeting the GPP rule there is the challenge of meeting the public procurement rules and environmental legislation. They, therefore, suggest that GPP policy should be made to be clear in terms of scope procurement activities and all the relevant external and internal stakeholders should be engaged during the planning process to enable feedback to be received to enhance easy implementation (Environmental Protection Agency 2014).

DRIVERS AND BARRIERS TO SUSTAINABLE CONSTRUCTION

The drivers and barriers to sustainable construction as identified by (Adetunji et al., 2003; Meehan & Bryde, 2011; Opoku et al., 2015; Qi, Shen, Zeng, & Jorge, 2010) are

- good organizational leadership;
- environmental and government policies;
- good sustainable procurement policies and gaining a competitive edge.

While some of the barriers are:

- the industry culture;
- the fragmented nature of the construction industry;
- rigid specifications and client's unwillingness to share risks.

For example, The Environmental Protection Agency (EPA)reported that some of the concerned and barriers in implementing GPP in the public sector are costs, annual budget constraints, lack of support for GPP from senior management, risk of legal challenges, complexity of verification, the effect of central procurement frameworks, and lack of resources (Environmental Protection Agency 2014).

Furthermore, Meehan & Bryde (2011) explained that the drivers of sustainable construction could be either internal or external. They argue that emphasis on internal drivers is what is likely to promote effective sustainable construction because previous studies have shown that sustainability in an organization is more of a policy-resistant dynamical system. They suggest that a strategic approach that needs to consider the triggers of sustainable development that will act as a catalyst in converting pressures into practices. Similarly, Riley, Pexton, & Drilling (2003), suggest that early involvement of the Contractor at the design stage can enhance meeting the sustainable construction objectives because of the Contactors organization in having the fundamental tools of the trade from value engineering to material procurement to sub-contractor communications and pricing. In addition, (McAuley, Hore, & West 2012) argue that implementing the adoption of Building Information Technology in the Irish Building sector will drive the attainment of meeting the Energy Performance Buildings Directive (EPBD). While Baker (2006) and Demaid & Quintas (2006) note that issues relating to sustainability should be treated as a primary focus rather than a secondary issue by building informal procedures into management process for managing projects. In their research, they found out that there is a need for interdisciplinary collaboration amongst partners involved in a project to manage knowledge effectively because planning for sustainability is quite complex and demands teamwork.

RESEARCH APPROACH

The method of data collection should be related to the type of information sought (Marshall & Rossman 2014). Marshall & Rossman (2014), further explained that the qualitative researcher relies on four different methods of collecting data, which are: participating in the setting, observing directly, interviewing in depth, and analyzing documents and material culture. This study adopts analysing the document to provide the basis for further empirical investigation in the future. The annual financial turnover of the top 50 construction contracting firms was obtained from the report published by the Construction Industry Federation (CIF) in 2016. The published company policies were critically examined to identify the various issues of sustainability in the policies. The research questions developed guided the study in identifying the key issues of sustainability in the various organisational policies. The research questions raised in the study are:

1. How is sustainability disclose in the various company policies?
2. How do the policies address the triple bottom line (TBL) of sustainability?
3. How do the policies address issues of change in organizational culture?
4. Who is responsible for issuing or addressing such policies?

The results were analysed using descriptive statistics and presented in charts and tables. Lessons learned from the top contracting firms need to be transferred to other smaller firms that are struggling with embedding the practice of sustainability. In addition, studies have shown that firms with high turnover tend to invest more on sustainability practice to enable them to gain a more competitive advantage (Adetunji et al., 2003; Boyd & Schweber, 2012; Zuo et al., 2012).

ANALYSIS AND DISCUSSION OF RESULTS

The company policy of the contracting firms was examined and issues about sustainability identified and recorded. The results were categorized and analyzed based on the firm's annual financial turnover, and nature/type of construction work undertaking. The results are grouped into three sets namely: clearly indicated, indicated or not indicated. Clearly indicated shows that a company clearly state their practice/ approach or willingness in practising sustainability, while not clearly indicated means issues of sustainability are only mentioned in passing or only an aspect of sustainability is stated. Not indicated shows that sustainability is not mentioned in the company policy. Table 1 provides the structure of the key metrics with examples used in analyzing the reports.

Table 1: Summary Key Metrics

Metrics	**Explanation**	**Example (s)**
Clearly Indicated	Clearly indicated shows that a company clearly state their practice/ approach or willingness in practising sustainability,	*"Sustainability brings together the three pillars of society (people), environment (planet), and economy (profit). ABC coy responsibility is to ensure that its operations meet the needs of the present without compromising the ability of future generations to meet their own needs"*
Not Clearly Indicated	Not clearly indicated means issues of sustainability are only mention in passing or only an aspect of sustainability is stated.	*"BZY company recognizes that slavery and human trafficking remains a hidden blight on our global society. The aim of the company is to identify our responsibility by alerting staff to the risks, however small, in our business and in the wider supply chain. Staff are expected and encouraged to report concerns to management, where they are expected to act upon them"*
Not Indicated	Not indicated shows that sustainability is not mentioned in the company policy	There is no any policy stated

The results in figure 1 show that only 14% (7) of the firms have a clearly stated policy on sustainability while 34% (17) only indicated. Emphasis was more on environmental issues and some on social issues related to corporate social responsibility (CSR) for companies that only indicated. For example, one of the contractors emphasized the need for minimizing and eliminating environmental impact and implementation of the environmental management system. Company X, for instance, stated,

"X Company recognizes that construction operations can have a damaging impact upon the environment and therefore will ensure that all construction activities to be carried out in such a manner to ensure as far as is reasonably practicable, a high standard of environmental protection and awareness".

Another Contractor emphasis was on corporate social responsibility by re-emphasizing to abide by the modern-day slavery act 2015 policy by ensuring that all staff has a sense of belonging to the company and the society protected from danger. The chart in figure 2 shows the area of emphasis of Contractors with not clearly indicated policies.

Similarly, 52% (26) do not have any statement in their policy on sustainability. In terms of change in organizational culture, most of the firms understand the importance of teamwork, communicating their activities and workers motivation to enable them to realize their sustainability goal. For instance, one of the firms states that *"…. we must work in partnership with our stakeholders. A positive difference will be achieved through collaboratively developing innovative solutions, providing education and development, and pro-actively engaging our local communities…"*
In terms of leadership drive, the managing director of the corporations signed the standalone sustainability policy. This goes to show their level of commitment and desire in promoting sustainability practices in their various organization.

The summary of these results provides a snapshot of what the contracting firms' policy on sustainability indicates and provides further support to Berry & McCarthy (2011) argument that construction firms are beginning to address sustainability in their organizational policy.
Furthermore, analysis of firms' financial turnover and nature of work undertaken is carried out as shown in the next sections.

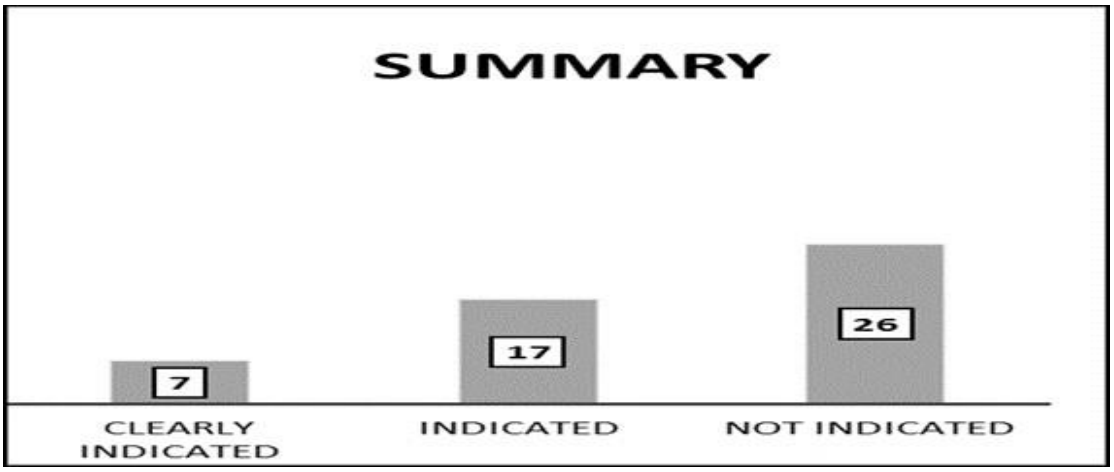

Figure 1: Summary of Results

Figure 2: Results of Not Clearly Indicated Policy

ANALYSIS BASED ON ANNUAL TURN OVER

The annual turnover was categorized into four categories between €300million and above to the least of €0-€50million. As presented in Table 2, the result shows that 50% of companies with an annual turnover of €300million and above have their policies on sustainability clearly indicated while 50% of companies do not a have clearly indicated policy on sustainability. However, companies with annual turnover of €100 to €299million have 22% of the companies with a clearly indicated policy on sustainability while 11% indicated and 67% did not indicate any policy on sustainability. Companies with annual turnover of €50 to €99 million did not have any clearly indicated policy on sustainability but have 50% indicated and not indicated. Finally, in categorization based on turnover, companies with €0-€50million turn over had only 7% of the

companies with a clearly indicated policy on sustainability and 45% and 48% of the companies had only indicated and not indicated policies as shown in Table 2. Examining the different organizational policies, the firms that have clearly indicated their policy on sustainability refers to gaining competitive advantage through responsible sourcing, engaging community and recycling of waste and other construction products. This also supports and confirm the assertion of Adetunji et al (2003) and (Zuo et al., 2012) that companies with high turnover are likely to address sustainability in their organizational policy.

Table 2: Policy on Sustainability Based on Turnover

TURNOVER	CLEARLY INDICATED	INDICATED	NOT INDICATED
300M AND ABOVE	50% (2)	0% (0)	50% (2)
BETWEEN 100 TO 299M	22% (2)	11% (1)	67% (6)
BETWEEN 100 TO 299M	13% (1)	38% (3)	50% (4)
BETWEEN 100 TO 299M	7% (2)	45% (13)	48% (14)

ANALYSIS BASED ON NATURE/TYPE OF WORK

The type and nature of work undertaking by the construction firms were further examined as presented in Table 3. The results show that construction companies that undertake General Building works and Civil works and only Building works have a clearly indicated policy of 33% and 13% while the other companies only indicated or did not indicate any policy on sustainability. The level of commitment of firms to promoting sustainability is likely to be dependent on the stage/phase they were engaged in the project and the type of procurement method used. For example, in most construction projects the mechanical and electrical contractors and Aluminium, glazing works, windows, and Joinery and interiors contractors are engaged as subcontractors. They are not fully involved in the tendering and planning process, this could inform their low response to sustainability. While the contracting firms that are involved in building and civil works to enhance their competitive advantage have sustainability as a major policy in their organizational policy. These results provide an insight to investigate further the assertion of Berry & McCarthy (2011) by examining how contracting firms engage sub-contractors to achieve responsible sourcing. Even though most of the firms have indicated their engagement or willingness to in engaging their supply chain in meeting sustainability agenda.

Table 3: Policy on Sustainability Based on Nature/Type of Work

NATURE OF WORK	CLEARLY INDICATED	INDICATED	NOT INDICATED
General Building works and Civil works	33%	27%	40%
General Building works	13%	53%	33%
Civil works	0%	20%	80%
Mechanical and Electrical	0%	25%	75%
Mechanical Works	0%	0%	100%
Electrical Works	0%	50%	50%
Aluminium, Glazing works, Windows, and Joinery and Interiors	0%	50%	50%

DISCUSSION: IMPLICATION OF EARLY RESULTS

These early results provide a snapshot of how sustainability is address by the top contracting firms. The results emphasize and confirm the report of Berry & McCarthy (2011) on the gradual willingness of large firms in embedding sustainability in their organizational policy and the move to embed sustainability in their practice. In addition, the results also confirm the study carried out by Akotia, et al. (2016), Opoku & Ahmed (2013), and Essa & Fortune (2008), which explains that the construction sector understanding on sustainability is limited more to the environmental aspect.

The results provide the context and an insight to an understanding on how the financial turnover, nature, and type of work undertaken by contracting firms can drive the promotion of sustainability. Finally, the early results provide a focus for the next phase of the research by going in-depth to find out how the internal drivers influence the promotion of sustainability practices as suggested by Meehan & Bryde (2011) and also how procurement practices can promote sustainable construction practice.

CONCLUSIONS AND FUTURE RESEARCH

In conclusion, this study unveiled how top construction contracting companies address the issues of sustainability in their organizational policy and practice. This result provides a feedback that will enable further research on the barriers affecting companies that are not active in promoting sustainability through their organizational policy. In addition, further investigation on the level of implementation of the stated policies to enable identification of the drivers and barriers to promoting sustainable construction in the Contractors organization is necessary. This will be carried out by examining how firms undertake their procurement process and the various enablers (people, risks and opportunity abd assesment, engagement, measurement and leadership and governance) are managed to drive sustainable practices in the constructioncontracting organisations.

As the AEC sector continues to address the goals of sustainability in their organizations and get beyond the challenges of the climate change agenda. Even that organization, as identified in the research that has sustainability as a top priority in their policies struggle with making that change and addresses their sustainability policies and issues differently. Sustainability and knowledge of our evolving technological driven society are key skills in a world of rapid change and unpredictable unknowns. The leading AEC sector construction firms are rapidly evolving, and new formats of processes and transactions developing at an unprecedented rate. The challenge is to do this at a sustained rate.

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IDENTIFYING MEASURES TO INCREASE PROCUREMENT OF NET-ZERO CARBON RESIDENTIAL BUILDINGS IN SOUTH AFRICA

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Abstract

Climate change poses a massive threat to humankind. It therefore demands attention from both the public as well as governments. Homes are primary contributors to global warming and environmental pollution, meaning a conversion to net-zero carbon homes will drastically help counteract this negative environmental impact whilst offering a sustainable healthy living environment for its residents. The aim of this research is to investigate possible reasons why high income clients are not procuring net-zero carbon homes in South Africa, thereby reducing their reliance on expensive, unreliable government supplied resources. The studies objectives were to identify if a single residential rating system and better education on the importance of reduced energy, water and materials consumption would generate greater awareness and nudge high income clients towards net-zero carbon homes. Furthermore, it sought to investigate whether provision of additional capital to increase the uptake of these net-zero carbon homes, creating opportunities for banks, would provide an opportunity to lower GHG emissions generated in high-income residential homes in South Africa. The study employed a quantitative research approach using the survey research method with a non-probability snowball sample of affluent achievers as defined by the ACORN geodemographic classification. Conclusions drawn are that a large number of clear benefits exist for clients to procure a net zero carbon home in South Africa, however, little incentive from either government or funding institutions means clients remain reluctant to invest in the added expense as no major benefit accrues to them or the value of their property. Recommendations include the use of targeted education to inform high-income clients and funding institutions of the benefits, nudging both to place greater value on net-zero carbon homes. The implementation of a single trusted residential rating system would see a rise in the number of net-zero carbon homes procured in South Africa.

INTRODUCTION

Our homes and the environment are inextricably linked by the way we consume energy, materials, water and land during the construction and operation of these buildings (DCLG, 2008). Conventional residential homes are using up massive amounts of our nations resources annually whilst changing the public's perceptions on the importance of a sustainable built environment is challenging in any market, even more so within the conservative built environment culture in South Africa. (Allen & Crafford, 2015). Conventional homes are primary contributors to global warming and environmental pollution in South Africa (Brilhante, 2014). A simple conversion to greener homes, notably, net-zero carbon homes, will drastically help

counteract the environmental impact of these homes on our environment, creating a home which can offer a sustainable healthy living environment for its residents as well as their surroundings (Alias *et al.*, 2010). Barnes (2012) states that green building projects are not only intrinsically valuable, but can also serve as excellent vehicles for launching a broader community conversation about environmental issues.

The aim of this research is to investigate possible reasons why high-income clients are not procuring energy efficient housing options such as net-zero carbon in South Africa as a means of reducing their reliance on expensive, unreliable government supplied resources. The researcher's objectives were to: identify if a local single residential rating system would provide value to net-zero carbon residential buildings through greater awareness of and interest by high-income clients; discover if carbon tax levied on South African household consumption would incentivize procurement of net-zero carbon homes; identify whether clients needed to be better educated on the importance and benefits of reducing energy and water usage for residential dwellings; highlight opportunities for Banks' funding mechanisms to take into consideration the additional value add of GBFI's and; identify factors that could contribute to increasing uptake of net-zero carbon homes thereby lowering GHG emissions generated in high-income residential homes in South Africa.

NET-ZERO CARBON RESIDENTIAL HOMES

The value of net-zero carbon rated residential homes

Climate Change is one of the biggest problems the world has faced, posing a massive threat to the planet and demanding attention from both the public as well as governments (Broer & Titheridge, 2010). It is therefore vitally important that governments, developers and homeowners begin to take notice of the importance of practicing a sustainable lifestyle, not only to the benefit of themselves but our planet (WGBC, 2013). Apel *et al.* (2011) state that "Sustainable living is a lifestyle that is deeply satisfying, fulfilling, and appealing because it is socially, environmentally, and economically responsible." Choosing to live sustainably comes down to the choices you make as an individual to help improve and reduce any negative affects you may be contributing to the natural environment. The residential sector is a significant segment of the built environment that is responsible for using close to 70% of electricity produced annually (Coburn & Farhar, 2008). The key to helping preserve our natural environment from the effects of climate change and overuse of resources (Fortmeyer, 2006) is to make use of carefully thought out designs and advanced construction methods. This will allow for the successful creation of net-zero carbon homes that at a minimum enable annual output of renewable energy to equal that of the total amount of annual consumed/purchased energy from energy utilities.

Although it's ones choice to live a sustainable lifestyle with the negative effects of climate change looming over the planet, it's becoming more and more important that one makes any changes, large or small that can help preserve the planet and its resources. The behaviour and nature of social classes differ in the affects and contribution made to the environment. Higher earning individuals are not aware of the heavy effects their more lavish lifestyle is contributing

towards climate change compared to that of lower earning persons, with their lifestyle and usage contributing to both direct and indirect environmental impact. This is due to higher earners living in larger houses that consume more resources than those of lower earners, through powering the likes of their many home appliances (Janet *et al.*, 2011). According to the IPCC (2007), human operations are the largest contributor to both global warming and climate change by continually causing destruction to, and degradation of our precious natural environments, with the largest culprit our continual need to burn fossil fuels as a source of energy for our survival. In doing so, carbon dioxide gas is released into our atmosphere, which alters radiation cycles resulting in the abundance of properties found in our atmosphere leading to a warming or cooling of the climate system, which can have a detrimental effect on our planet.

Costs versus benefits in procuring net-zero carbon residential buildings

According to the IGBC (2014), the simple tangible benefits noticed are the straight reduction of between 20-30% in energy usage and 30-50% water saving, ensuring that the benefits and cost reduction from procuring of a net-zero carbon building can be realised. The intangible benefits of a net-zero carbon home are simply the enhanced quality of life it brings to the occupants (Berry *et al.*, 2017). Investigation from Hamit-Haggar (2012) suggests that the energy industry is the greatest contributor towards the planets carbon dioxide emissions (Yingkui & Solgaard, 2015). To restrict the industry from continuing to cause further damage to the natural environment and its inhabitants, various protocols to limit and reduce carbon dioxide levels globally need implementing. Currently in South Africa, no policies or laws exist that pose any limits/restrictions, or govern any assessment of a household's performance in terms of their carbon footprint. The South African government needs to step in and create sound, fair policies in terms of sustainable development practices, not only focusing and incorporating plans for the commercial business sector, but also to accommodate for the large residential property market as well (Newell *et al.*, 2014).

Looking into the domestic housing sector, there are various methods government could employ to target reducing carbon emissions. Government may in the future offer a number of incentives for the creation of green developments, in the form of density bonuses and subsidies or grants (Pitts & Jackson, 2008). Strategies should include penalising any individuals for a poor carbon emission performance, which can create a positive source of income to serve as capital that used for the development of new technologies and initiatives that help lower the total carbon footprint, with efficiency seen as crucial to the sustainability agenda (Newell *et al.*, 2014).

Climate Change is one of the most complex problems we have ever faced and has become a top global agenda item as a result. After the Paris Conference of the Parties meeting took place in 2015, African countries were signatories to compliance with the requirements to meet the aim of keeping the global warming temperature to less than 2 degrees centigrade above pre-industrial levels rather than the estimated 4 degrees centigrade according to the UN (Munang and Mgendi, 2016). In terms of the agreement, Africa will be speaking with one voice and is determined and committed to the inclusive, ambitious and equitable agreement ensuring the lowering of carbon emissions on the continent (GED, 2015).

Investment vehicles for a sustainable built environment are extremely limited. Whilst research conducted shows the clear benefits sustainable buildings bring, this is not taken into account in the valuation process (van der Sandt *et al.*, 2015). A direct link needs to exist between a buildings sustainability qualities and the effect they have on the home's value. Valuers need to obtain an in-depth knowledge and skill set on the subject to ensure an accurate valuation process exists that leads to a passive increase in investment in selfsustainable homes (Warren-Myers, 2013). A sound rating system, if enforced correctly, can create benefits not only for our over exploited environment, but also for the occupants of environmentally sustainable buildings in both the residential and commercial property markets (GBCSA, 2008).

Studies have been conducted in mature markets including those of Australia and some European countries that have found that green buildings, either commercial or residential, offer a variety of benefits not only to the environment but in economic terms as well (GBCA, 2008; Pitts & Jackson, 2008). A comprehensive, national, voluntary environmental rating scheme that evaluates the environmental design and construction of buildings at a macro level will provide the national property industry with a sound mechanism by which companies are recognised, as well as rewarded, for promoting health, productivity and well-being. A point rating system, incorporating certain mandatory requirements, would be a prescriptive approach to evaluating the performance of a building. The system needs to continually evaluate and update to ensure it is current with the latest technological advancements in the field (IGBC, 2014). The creation of a sound and uniform rating system will be a key ingredient in the success and creation of a competitive green building industry (Newell *et al.*, 2014). The benefits they create should lead to higher market value, lower operating costs, higher rental value / demand and higher sales value.

RESEARCH REVIEW AND METHODOLOGY

The demographic of the population for the purpose of this study is of the utmost importance as it enables us to gather a description of each individual relative to the respondents' location, interests and background. The research population consists of members of the public living within South Africa's major metropolitan areas who occupy a home and that can be categorised under the ACORN Groups differentiation of geodemographic classes, namely the Affluent Achievers titleholders. They must be able to carry at least one of three listed titles: Lavish lifestyles, Executive wealth and/or Mature money. The researchers used a nonprobability snowball technique to identify participants whereby the researchers' immediate family and friends provided the initial sample with additional participants drawn from their acquaintances across the country. Additional respondents were purposefully gathered in specific metropolitan areas in order to spread the sample pool evenly across the entire South African population within this affluent achievers group.

Research Method

The study made use of quantitative research as this relies on pure data from respondents, which is an approach that is extremely accurate due to the data being more focussed (Fellows *et al.*, 2003). A survey technique was employed to collect the data using a five point Likert

scale ranging from 'Not at all' to 'Definitely', with this being created online in order to get the most responses from the wide geographical spread of the population.

The researchers used a pilot study, conducted amongst the initial sample population, to ensure effectiveness as well as efficiency of the questionnaire before the link was distributed. In order to draw valid conclusions in respect of the sub-problems and hypotheses, the researchers used Excel to facilitate the necessary data analysis. The study conducted, made up of four sections, was analysed using various descriptive statistics including mean and mode values, to describe the data in a simple, easy to understand way and to draw conclusions (Keller, 2005).

RESEARCH RESULTS

Ninety-one (n=91) surveys were distributed around the country, with a response rate of 36.26% after thirty-three (n=33) replies were received and processed. The researchers deemed this sufficiently representative due in part to the distribution of respondents across the nine provinces of South Africa. KwaZulu-Natal (28%) and the Western Cape (21%) provided the largest number of responses. Figure 1 shows the responses for the other seven provinces, with the zero responses from the Northern Cape ascribed to the very low number of people meeting the criteria in a province with only 2.2% of the South African population (StatsSA, 2014). All the provinces with a 3% return rate have much smaller urban centres with large rural populations that would affect their sample in comparison with the major metropolitan centres located in Gauteng, KZN and the Western Cape.

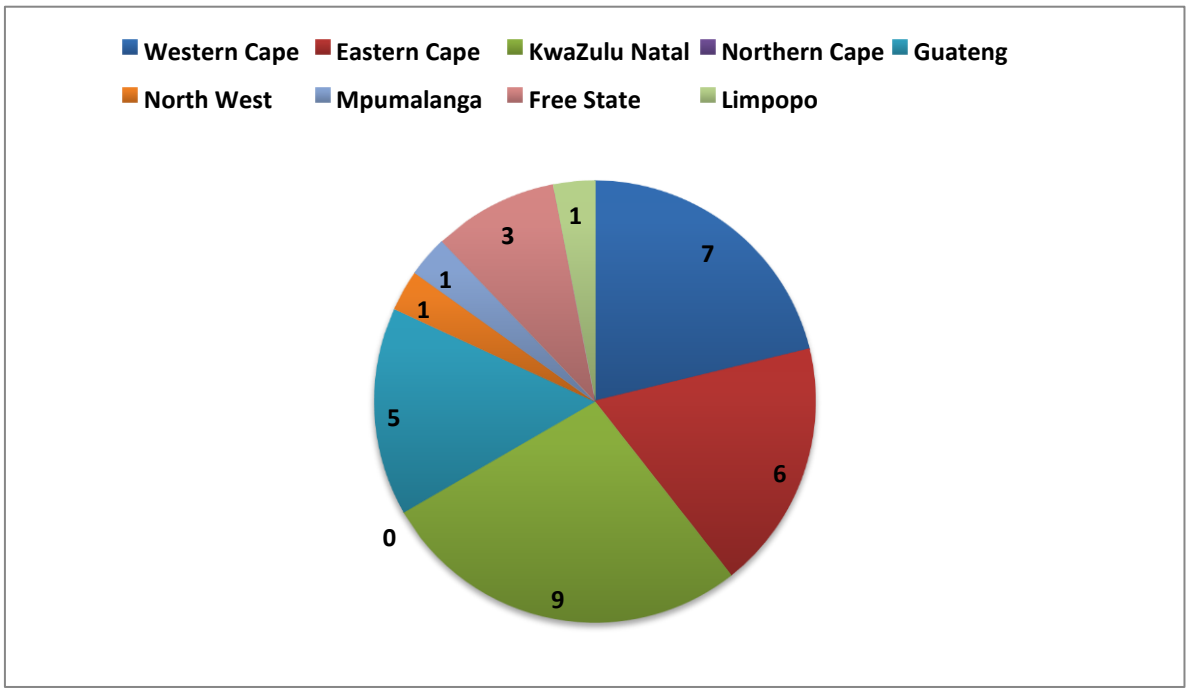

Figure 1. Provincial distribution – Number of respondents

Of the 33 respondents, 30 stated that they were or maybe were interested in a more sustainable lifestyle, of importance in gaining an understanding of the willingness of these

respondents to consider procuring a net-zero carbon home. Of the 33, 24 were already owners of the property they were occupying, so could potentially already have procured such a home. Just over half (n=17) had never incorporated any sort of green feature or innovation into their current or previous dwellings, which would appear to show the need for a nudge to start living the more sustainable lifestyle they were interested in.

When asking respondents if they would personally procure or at least contemplate procuring a net-zero carbon home based on additional information related to this home type, some notable aspects arise from the data collected (Table 1).

Table 1, Reasons to procure a net-zero carbon home.

	Response Rate (%)							
Aspect		**Not at all…….Definitely**					**MS**	
	U	**1**	**2**	**3**	**4**	**5**	**%**	**No**
If it would save you 40% on running costs.	0.00	0.00	3.03	9.09	9.09	78.79	4.64	**1**
If incentives were provided from your local municipality.	0.00	0.00	6.06	6.06	21.21	66.67	4.48	**2**
If its value would increase up to 15% on completion.	3.03	3.03	6.06	9.09	15.15	63.64	4.34	**3**
If, for example, carbon credit were available.	6.06	0.00	3.03	27.27	21.21	42.42	4.10	**4**
If government introduced penalties for excessive energy and water use.	0.00	3.03	0.00	30.30	33.33	33.33	3.94	**5**
Based on your current reasons for purchasing a home.	6.06	9.09	21.21	30.30	21.21	12.12	3.06	**6**

Firstly, if they knew the home could save them up to 40% on running costs (IGBC, 2014), more than three quarters (79%) stated they would 'Definitely' procure a net-zero carbon home. This achieved a research mean score high of 4.64 whilst the next two aspects, if incentives were provided from your local municipality and if the value would increase up to 15% on completion, also fell within this range. Viewed against the aspect that scored last on the table, would they procure a net-zero carbon home based on their current reasoning for a home purchase, which achieved an MS of 3.06, this further highlights that clients need a nudge to get them to 'buy-in' to the procurement of net-zero carbon homes.

On the question of whether certain drivers would 'incentivise' them to consider procuring a net-zero carbon home (Table 2), more than three-quarters (n=24 out of 33) of respondents were definitely willing to contemplate purchase of a net-zero carbon home should value be added to the property in the long term just because it was net-zero. Furthermore, they were also definitely willing to consider it if it meant they could maintain their current lifestyle without additional property taxes being levied, an MS of 4.33 being achieved. This highlights the important role municipalities and local government taxes can play (as opposed to national regulations) in nudging affluent home owners to lower their carbon footprint, a decentralised process envisaged by the Compact of the Mayors group, a key role player in nations achieving the nationally determined contributions as part of COP21 commitments. All the MS values were in the 'probably will' to 'definitely' range which would suggest that, by identifying specific

drivers, a much greater percentage of these ACORN respondents would procure net-zero carbon homes in the future, particularly if an added value could be attributed to the property as a result i.e. even if climate change were not to happen.

Table 2, Drivers to contemplate procuring a Net-Zero Carbon home.

	Response Rate (%)							
Aspect		**Not at all…….Definitely**					**MS**	
	U	**1**	**2**	**3**	**4**	**5**	**%**	**No**
It would add long term value to the property due to climate change.	0.00	3.03	3.03	9.09	9.09	75.76	4.52	**1**
It meant you could maintain your current lifestyle without increasing building taxes.	0.00	3.03	0.00	12.12	30.30	54.55	4.33	**2**
Your effects on the environment would decrease instantly as a result.	0.00	3.03	3.03	12.12	21.21	51.52	4.15	**3**
Government implemented an energy certification process.	6.06	0.00	6.06	15.15	39.39	33.33	4.06	**4**
A trusted rating system existed.	0.00	0.00	9.09	15.15	39.39	36.36	4.03	**5**

The researchers then asked respondents if government started to implement levies on buildings including carbon tax would this change their behaviour in relation to the use of those utilities (Table 3). After assessing the mean scores, which are mainly in the upper maybe range, it would appear to show that respondents are somewhat reluctant to change their way of living even if government were to implement a lifestyle tax across everyday utilities. A number of first world countries have implemented various forms of legislation with the aim of protecting the environment by penalising owners for any residential dwellings showing poor carbon performance (Newell *et al.*, 2014). This is useful for central government to understand how they can go about addressing the need to achieve the nationally determined contributions, a requirement of the COP21 agreement, as these customers may fight implemented levies rather than embrace them as an opportunity for savings in daily living expenses (detrimentally affecting carbon emissions targets).

Table 3, Influence of tax on utilities use towards a change in life styles.

	Response Rate (%)							
Aspect		**Not at all…….Definitely**					**MS**	
	U	**1**	**2**	**3**	**4**	**5**	**%**	**No**
The services (water/electricity consuming appliances) you are currently using.	6.06	3.03	9.09	30.30	24.24	27.27	3.68	**1**
The amount of electricity you are currently using.	3.03	12.12	12.12	24.24	24.24	24.24	3.38	**2**
The amount of water you are consuming.	3.03	9.09	12.12	33.33	18.18	24.24	3.38	**3**
The lifestyle that you live.	6.06	9.09	12.12	36.36	12.12	24.24	3.32	**4**

The next aspect under review focused on respondents' personal beliefs with respect to climate change, sustainability and net-zero carbon homes. Looking at the results in Table 4, two-thirds

definitely agreed that the homes we live in should be incorporating some sort of green innovation (MS 4.48) and that we should be taking precautions to minimise the amount of electricity being consumed (MS 4.42). Water came in with a slightly lower Mean Score of 4.18, whilst a slightly lower percentage but still more than half definitely agreed that climate change poses a threat to our natural environment (MS 4.30). Notably, six out of seven aspects had a mean score of 4.00 or more and the lowest MS at 3.97 related to the cost of the utility, continuing the theme from Table 3 that money is not a driver for behaviour change nor will it enable emissions reduction resulting from penalising that behaviour.

Table 4, Alternative energy solutions with most potential to reduce energy dependence.

	Response Rate (%)							
Aspect		**Not at all…….Definitely**					**MS**	
	U	**1**	**2**	**3**	**4**	**5**	**%**	**No**
The homes we live in should be incorporating some type of green innovations.	0.00	0.00	9.09	0.00	24.24	66.67	4.48	1
Humans should be taking precautions helping to minimise the amount of electricity they consume.	0.00	0.00	9.09	9.09	12.12	69.70	4.42	2
Climate change poses a massive threat to our natural environment.	0.00	3.03	6.06	9.09	21.21	60.61	4.30	3
Humans should be taking precautions helping to minimise the amount of water they consume.	0.00	0.00	9.09	15.15	24.24	51.52	4.18	4
Climate change poses a massive threat to the human race.	0.00	3.03	12.12	3.03	33.33	48.48	4.12	5
All new housing developments from today should be fully net-zero carbon.	3.03	0.00	6.06	24.24	30.30	36.36	4.00	6
You are currently spending too much money on water / electricity.	6.06	6.06	9.09	15.15	15.15	48.48	3.97	7

In stating that cost is not a driver, it is then of interest to see the results from the following two questions that asked whether those surveyed had indeed looked to reduce their impact on the planet by investigating and then investing in renewable or at least sustainable energy or water solutions. A vast majority of the respondents, 70% (n=23 of 33), had investigated alternative sources of power, with a smaller percentage (n=15) investigating alternative water source solutions. However, only 39% (n=13 of 33) had actually gone on to invest in alternative sources of power, whilst 14 of the 15 who investigated the water solutions had gone on to invest in them. This identifies an appetite for change and that opportunities exist to convert a greater percentage of the investigators into investors. It also suggests that education might not be the only reason behind the selected population not procuring into the idea of sustainable energy and net-zero carbon homes, with capital cost possibly outweighing lifetime cost benefit, particularly for energy, which requires a much higher capital outlay. Age data was not part of the survey so ascertaining whether the population were a category that may have had a more short-term goal to this investment is not possible.

The researchers sought the opinions of respondents on those factors funding institutions could consider implementing to lower interest rates for net-zero carbon homes, based on the benefits in the long term versus the higher initial capital cost. More than half (19 out of 33) are of the opinion that there is definitely a need for funding institutions to reward customers

for the investment of sustainable features in their homes (MS 4.24). Furthermore, when asked if they would recommend that their funding institutions take into consideration sustainability of the dwelling when making valuations, the majority of the sample agreed, an MS of 4.15 being recorded. Respondents to a lesser extent perceive the higher expense in the procurement of a net-zero carbon home as a worthy investment, an MS of 3.91 being achieved, whilst their current stance on the procurement of a net-zero carbon homes will likely change should the funding institutions make this change. Notably, respondents had less interest in the idea of procuring a dwelling with a higher valuation if instalments are similar but for a longer period, an MS of 3.39 achieved, just outside the 'Probably Will' range.

Table 5, Impact of factors funding institutions consider for lowered interest rates on netzero carbon homes

	Response Rate (%)							
Aspect		**Not at all…….Definitely**					**MS**	
	U	**1**	**2**	**3**	**4**	**5**	**%**	**No**
Do you believe funding institutions should reward customers for investing in Net-Zero Carbon Homes?	0.00	3.03	3.03	18.18	18.18	57.58	4.24	**1**
Would you recommend that your funding institution take the sustainability of a dwelling into consideration when making its valuation?	0.00	3.03	6.06	12.12	30.30	48.48	4.15	**2**
Would you still perceive the higher expense in the procurement of a net-zero Carbon Home a worthy investment in the end?	3.03	3.03	9.09	21.21	24.24	39.39	3.91	**3**
Would your current stance on procuring a net-zero Carbon Home change?	3.03	3.03	12.12	24.24	27.27	30.30	3.72	**4**
Would the large initial start-up cost still deter you from purchasing a net-zero carbon home?	3.03	6.06	0.00	27.27	48.48	15.15	3.69	**5**
Would you procure a house with a higher value if your instalments were similar but for a longer period?	6.06	15.15	9.09	21.21	27.27	23.24	3.39	**6**

DISCUSSION

The study determined that in the presence of various incentives provided to clients for the investments in GBFIs, their current stance on procuring net-zero carbon homes could change. In fact, many higher income persons are aware of various forms of green innovations that are currently available have investigated their use and firmly believe that precautions be taken by households to fight the threat of climate change whilst ensuring valuable monetary savings. However, less than half of the sample's respondents had incorporated some form of green innovation to achieve savings in any property they had owned, despite 90% maybe being interested in a more sustainable lifestyle. Further evidence showed that government interventions such as carbon tax lack sufficient incentive to reduce the target populations' consumption of water and electricity. The researchers discovered that should a carbon tax be levied on South African high income household consumers, this would not on its own incentivise procurement of net-zero carbon homes as this ACORN group have the disposable income to pay to keep themselves living the same lifestyle. More sustainable purchases in the form of homes as well as appliances may result, allowing their lifestyle to remain the same but lowering consumption levels.

In assessing whether clients need to be better educated on the importance and benefits of containing operational costs for residential dwellings, the research identified that many are already well educated. However, they are not incentivised enough to act on that education, other than where it has become a necessity due to the likes of drought or load shedding as experienced with electricity in 2008. Almost all those investigating water savings options went on to procure savings mechanisms (although less than 50% had investigated), the worsening drought at the time these respondents were surveyed possibly impacting on this particular result. In contrast,

The study determined that a strong relationship exists between the cost of green innovations, and their procurement, as they come at a higher cost to the user. Valuers are a barrier for investment in sustainable housing, as they continue to exclude the sustainability initiatives within their evaluations (Warren-Myers, 2013; van der Sandt *et al.*, 2015). The study established that by identifying a local single residential rating system it would provide value to net-zero carbon residential buildings through greater awareness of and interest by high-income clients. The study obtained results suggesting that if funding institutions established various mechanisms to encourage the public procurement of such, GBFIs would increase thus decreasing the cost of these products, encouraging even greater uptake of low or net-zero carbon homes.

CONCLUSION

Through various sources, the researchers established that a large number of benefits exist surrounding net-zero carbon homes and potential clients are well educated on these benefits. However, these clients remain reluctant to invest in the added expense of GBFIs as it is of no major benefit in terms of the assigned value. The study determined that a strong relationship exists between the cost of green innovations, and their procurement, as they come at a higher cost to the user. Although running costs may be lower, there is no incentive from government through reduced taxation to offset additional expenses to construct. Larger monthly payments remain with funding institutions showing no encouragement through green bonds to change the way South Africans construct their homes. This poses a challenge to the growth of net-zero carbon home procurement, which could be the key to revolutionising the housing sector for all sectors of the population, thereby lowering GHG emissions generated by homes.
South Africa should investigate various successful green valuation-rating systems so it can incorporate these into the valuation of residential dwellings, ensuring fair credit for the presence of GBFIs. By simply creating a single trusted residential rating system that incorporates the green performance benefits of a building, the number of individuals procuring net-zero carbon homes would rise due to owners achieving a return of more than a quarter over the current value of their investment. Government should implement an incentive driven carbon tax, penalising all individuals who exploit natural resource use, with funds collected being used to aid greater uptake of net-zero through a programme of targeted education and local government tax credits. Funding institution valuers need to be rewarding their clients with the value the presence of these green features/innovations bring to properties, ensuring that their initial expense is a worthy long-term investment for clients.

From a young age, citizens of South Africa should be educated on the responsibility each individual carries to protect and preserve the natural environment, creating a more sustainable society for all. Through targeted education, the population may be enlightened on the benefits of procuring net-zero carbon homes thus increasing their procurement in South Africa. Net-zero carbon homes aim to create a sustainable future which reduces our overall carbon footprint as well as striving to create a more economically viable, environmentally friendly and energy efficient property stock, carrying long term benefits for a healthier, more sustainable lifestyle in South Africa.

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GREEN PROCUREMENT FOR MUNICIPAL CONSTRUCTION PROJECTS

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Keywords: Construction, environmental friendly, green procurement, municipal

ABSTRACT

Green procurement is the tool used by governments to source the supply of products and services that are environmentally friendly to counter the global problem of climate change. The study is a qualitative investigation of the implementation of green procurement in the construction sector at local government level. To realise an extended comparative perspective, the Nelson Mandela Bay Municipality and three smaller municipalities were reviewed. The study commences with the exposition of the aspects of green procurement from the basis of the enabling legal framework to the scholarly contribution from which the study can be predicated. It becomes apparent from this review of legislation that there is scope within the existing body of legislation for the use of green procurement as an environmental tool. The review of literature indicates that development has a negative impact on the environment, which includes vegetation loss, illegal dumping, and greenhouse gas emissions. Furthermore, the literature recommends green lifecycle design, and construction projects to reduce the impact of construction on the environment. A systematic investigation of municipalities by means of interviews with relevant municipal officials involved with the procurement of products and services, infrastructure services and environmental affairs officials made it possible to identify factors that impact on the implementation of green procurement. The investigation determined that the major obstacles to green procurement are: socio-economic challenges that confront municipalities; lack of policy, and lack of awareness. Recommendations include the proposal of initiatives that encourage and improve the implementation of green procurement.

INTRODUCTION

The construction industry is one of the industrial sectors that have a direct impact on the natural environment. Construction projects typically result in carbon dioxide (CO_2) emissions and all other greenhouse gases mostly expressed as CO_2 equivalent that correspond to their respective impact on climate change (Bresnen and Marshall, 2014). Additionally, Lehtiranta, Sanchez, Hampson and Kenley (2012) argue that the largest ecosystem impacts measured on the global level are caused by greenhouse gas emissions. Across the world, public authorities are increasingly aware of the environmental impacts and their responsibility to reduce them (UNEP, 2009). According to Turley and Perera (2014), taking environmental preferences into consideration is regarded as one of the incentives to promote environmental friendly business. This is why it is being encouraged by most government authorities in many countries. In the

United Kingdom (UK) for example, procurement has been used as lever to help government reduce its environmental impacts, most especially carbon emissions for over a decade (Marron, 2012). A comprehensive policy framework developed over many years together with ambitious objectives, targets and regular reporting have provided the right conditions for the public sector to show leadership in this field (Hanks, 2013).

The National Climate Change Policy (White Paper) identifies construction as one of the priority sectors for adaptation and mitigation (TrustSA, 2011). It is therefore very important for local government entities to start investigating sector strategies for reducing Green House Gas (GHG) emissions to feed into the national trajectory. Ofori, Gang and Briffett (2002) contend that the application of green procurement can be an effective sector strategy for reducing environmental impact in all the stages of the construction process. Odhiambo and Wekesa (2010)share the same sentiment that green procurement systems have been promoted to mitigate construction waste and to achieve better project performance. Green procurement particularly for public entities as a way to improve environmental footprint is a wellestablished and fast developing concept. Whilst implementation models may differ, the use of agreed minimum environmental product specifications is widespread and appears to be the main mode of delivery widely supported by governments (Ochoa and Erdmenger, 2010). In a study conducted by Thomson and Jackson (2007), the researchers investigated the commitments of the UK government towards sustainable development. The study focused on green procurement in local government which determined that, although green procurement had been encouraged through legislation, it had lost its momentum during implementation.

In South Africa, the government is the largest buyer in the country (TrustSA, 2011). On average, 11% to 15% of the national Gross Domestic Product (GDP) and 20% of the NMBM Gross Geographic Product (GGP) is spent on public purchasing (Nhamo and Pophiwa, 2014).
It is also estimated that the public sector spends 45% to 65% of their budgets on procurement (National Treasury, 2013). Given this substantial purchasing power, the public sector has enormous leverage to stimulate and drive markets for sustainable production and consumption when they make a determined effort to purchase green products and services. This purchasing power also puts local authorities in a prime position to promote environmental friendly business activities through public procurement policies that encourage sustainability. Effective government policies have a positive, long term downstream impacts in the industry. Therefore, government is well positioned to lead the industry by creating the right green procurement innovation environment to flourish.

In an attempt to promote sustainable development, the Ministry of Finance together with the Ministry of Public Works jointly created the public sector procurement reform initiative as a commitment towards a sustainable future for it citizens and also in support of its overall economic objectives (Republic of South Africa (RSA), 1997). This is also in line with South Africa's legal obligations under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, South Africa has committed to implementing greenhouse gas emission reduction plan initiatives (TrustA, 2011). Contextually within South Africa, it is well understood that green procurement can be very effective in controlling construction activities to ensure environmental sustainability (Nhamo and Pophiwa, 2014). However, policies for green public procurement are yet to be implemented in the public sector (Nelson Mandela Bay Municipality (NMBM, 2010). Although focus has begun to shift from managing the government

estate in a sustainable manner to engaging in dialogue with government suppliers to effect change downstream. Yet, South African municipalities still lag behind in comparison to other developing and developed countries in terms of green procurement implementation (Perera, Chowdhuryn and Goswami, 2007). Arguably, proper implementation strategies need to be researched to encourage implementation of green procurement. This elevates the need to conduct further research relative to green procurement strategies. Against this backdrop, the aim of this article is to present findings of a study that analysed and reviewed the implementation of green construction procurement within the context of local government in South Africa.

GREEN PROCUREMENT CONCEPT

Green procurement is not unique in South Africa, but, a phenomenon practised around the globe that encourages positive impact on the environment and human health (UNEP, 2009). The United Nations Development Programme (UNDP) defines green procurement as the purchase of products and services which have less impact on the environment in comparison to other products and services that serve the same purpose (UNDP, 2008:11). Green procurement takes into account environmental criteria when purchasing goods and services to ensure that the related environmental impact is minimised (Streimikiene and Girdzijauskas, 2007). In a similar vein, Lehtiranta *et al.* (2012) define green procurement as the practice of formulating environmental requirements in the tendering process, or more broadly to the process of applying environmental considerations into planning, contracting and monitoring the project delivery, including the use of environmental criteria in the selection of contractors.

Commonly known as Green Public Procurement (GPP), green procurement for public entities is defined as a process whereby organisations meet their needs for goods, services, works and utilities in a way that achieves value for money on a whole life basis in terms of generating benefits not only to the organisation, but also to society and the economy, echoing the minimal damage to the environment (European Union, 2001). Green public procurement addresses areas such as the purchase of energy-efficient buildings, office equipment constructed from environmentally sustainable timber, recyclable paper, environmentallyfriendly public transport, electricity stemming from renewable energy sources and air conditioning systems complying with environmental solutions. The environmental attributes of such green products are the use of less toxic materials, energy and water efficiency, and the use of recycled material (Economic Development Department, 2011).

Developed countries have been engaging in green procurement as a mitigating strategy for over two decades whereas developing countries are only towing along. In South Africa, sustainable public procurement has incorporated green procurement through its legislation (RSA, 1996). Though not explicitly stated as a law, most procurement officials do not see it as mandatory and therefore, do not take it seriously. A study by Department of Environmental Affairs on assessment of green procurement practices in South African metropolitan municipalities reveals that, green procurement has been implicitly expressed in South Africa's legislation (RSA, 1998). Provincial governments such as the Western Cape have tried to incorporate green procurement into their procurement process. This has been done by entrenching environmental criteria into the five elements of the supply chain management process namely, demand management, acquisition management, logistics planning, disposal management and

supply chain performance (Turley and Perera, 2014). By incorporating green procurement guidelines into the specifications and the approval of contracts, Turley and Perera (2014) argue that the institution can influence the manufacture and sale of environmentally friendly products it procures by assessing the environmental impact of materials used for production during design, manufacture use and disposal. This will ensure that governments' economic growth translates into green conscious development. Local government, on the other hand, has not fully caught up with the idea. An engagement with almost all the metropolitan municipalities in South Africa has proven that a lot still needs to be done in terms of green procurement for a developing country such as South Africa to be able to be at par with its developed counterparts (Corporate Governance and Traditional Affairs (COGTA), 2013).

Barriers and challenges to Green Procurement

A number of barriers have been identified in the construction industry in an attempt to implement other procurement advances which may apply to sustainable procurement. Some of these are lack of green procurement policy (NMBM, 2010), lack of awareness (Reijniers and Tazalaar, 2008), concerns about the quality of sustainable products, supplier availability (Walker and Brammer, 2009), product availability (Walker and Brammer, 2009; Li and Geiser, 2005), lack of innovation (NMBM, 2010), lack of regulation, guidance and enforcement (Powell *et al.,* 2006; NMBM, 2010).

Lack of green procurement policy

A policy stating the organisation's position regarding green procurement is vital to provide clear aims and objectives and to act as a driver for all those working within the organisation (NMBM, 2010). Without a policy a universal approach cannot be achieved, as there is no guidance for people on what should be done and why it should be done. Insufficient resources dedicated to green procurement, lack of communication regarding the policy and conflict with the preferential procurement policy are major barriers preventing the implementation of green procurement at the municipality level (NMBM, 2010).

Lack of awareness

Lack of promotion and lack of awareness within the organisation of green procurement, its benefits and external drivers impede the implementation of green procurement (NMBM, 2010). Given that information and awareness is vital to ensure that all those within an organisation understand what they need to do, why they need to do it, how they need to do it, and where they can access guidance. This can assist with change management and increase commitment within the organisation. For an organisation to participate, it must have an understanding of concepts, vocabulary, and terms (Reijniers and Tazalaar, 2008).

Poor supply market

A sound supply of green products and services is a key requirement to implementing green procurement. Without suitable suppliers, an organisation cannot actively select to procure green options (Walker and Brammer, 2009). There is a perception that green products are more expensive than conventional alternatives. This is true in some cases particularly where

development costs are reflected in the price, however; often there is no significant difference (Li and Geiser, 2005). The real problem may simply be that products are being ordered in small quantities, or are not available locally. Sometimes a green product may have a higher up front purchase price, but will cost less over its lifetime. Frequently, local distributors do not stock green products, or else they stock small quantities, which may lead to delays in obtaining the product (Walker and Brammer, 2009).

Lack of innovation

Buyers are hesitant to use unproven products or materials (NMBM, 2010) because green procurement is relatively new to many organisations. Innovative and proactive measures may be needed to kick-start its implementation. Another barrier to green purchasing can be simply a lack of acceptable alternatives to the present products. However, growing demand will stimulate the development of new and better green products (NMBM, 2010).

Lack of regulation and enforcement

Changing behaviour can be difficult to achieve in organisations. Thus culture, which effects the attitude, mind-set, and commitment of the organisation and its staff to sustainable development may impact on the implementation of green procurement in organisations (Reijniers and Tazalaar, 2008). Enforcement and regulation is a key way of ensuring that new policies and initiatives are adhered to, and ensuring that green procurement can be implemented.

Environmental impact resulting from the construction industry

Literature suggests that development has a negative impact on the environment such as vegetation loss, illegal dumping, and GHG emissions (Odhiambo *et al.*, 2010; Van Wyk, 2007). Furthermore, it indicates that these impacts can be reduced by green life cycle design of construction projects.

Vegetation loss

Odhiambo *et al.* (2010) state that construction activities consume 50% of all resources globally, 70% of all global timber products, and 40% of energy consumed. The consumption of these resources adversely affects the environment through over-exploitation of both renewable and non-renewable resources, namely materials and energy. Over-exploitation, for example, of building materials may result in the stripping of top soil and destruction of the natural topography, resulting in problems such as soil erosion, landslides, and loss of fertile soil for farming and detrimental effects on local hydrology (Odhiambo *et al.,* 2010).

Illegal dumping

Construction and demolition waste account for 50% of all waste prior recovery (Odhiambo *et al.,* 2010). A study revealed that the illegal dumping of waste by contractors and the general public is rife in the Nelson Mandela Bay metropole. The total volume of waste according to the study was 8 985m^3. This value indicates excessive amounts of dumping in the metropole raising

concerns in terms of the long term environmental impact (NMBM, 2010). One of the strategies adopted by the NMBM to deal with illegal dumping is green procurement. As a result, the NMBM has embarked on developing a green procurement implementation strategy to be incorporated into the NMBM's procurement activities (NMBM, 2010). However, the follow up and management control of the process is still lagging behind (Behrens, 2010).

METHODOLOGY

Research approach

This study was conducted using a qualitative approach with a focus on acquiring in depth knowledge and understanding of green procurement as an option for municipal construction projects. To achieve the purpose of the study, case studies were conducted among selected municipalities in the Eastern Cape Province. According to Yin (2009), a case study allows researchers to explore individuals, organisations, communities and programs, to test research mechanisms and techniques. In addition, case studies are carried out to explore a phenomenon in context using a variety of data sources (Zainal, 2007). A multiple case study design, consisting of a replication approach to four cases, is used in this article (Zainal, 2007). According to Yin (2009), there is no ideal number of cases that should be undertaken. There are eight metropolitan areas situated in six provinces in South Africa and 226 local municipalities in South Africa. Given that the case study area was in the Eastern Cape Province, purposive sampling method was used to select one metro and three small municipalities, namely Nelson Mandela Bay Municipality, Ndlambe Local Municipality, Makana Local Municipality, and Sunday`s River Local Municipality.

These case studies were selected on pragmatic considerations, namely their availability and the convenience of being in close proximity to the location of the researcher. This facilitated effective access to relevant people and information. In each metro and municipality, officials from supply chain, infrastructure delivery and environmental departments were interviewed, in total, 10 respondents were interviewed. It was determined that top officials from supply chain, infrastructure delivery and environmental departments would be better suited for the interview.

Method of data collection

The data sources were identified through judgment sampling technique. Secondly, the target sample population was contacted to request interview sessions. A semi-structured interview questionnaire, as described below, probed the institution's readiness to implement green procurement practice. Officials from the four selected local authorities were interviewed faceto-face or telephonically. Each interview session took forty-five minutes to complete. The researcher asked the questions and used a recorder to capture the responses. A three part questions guided the interviews. Section 1 - Relates to respondents' familiarity with the concept of green procurement and how green procurement could act as a driver to curb environmental degradation issues such as vegetation loss and illegal dumping of construction waste. Section 2 - Explored respondents' opinions regarding the barriers to implementation of green procurement. Section 3 - Relates to environmental management practice, enforcement and control measures to ensure compliance during construction.

Method of data analysis

The data were analysed using a thematic analytical technique. Rather than being rooted in theory, this technique is centred on developing categories based on participant responses and the resulting data (Fossey, Harvey, McDermott and Davidson, 2002). According to Aronson (1995), thematic analysis identifies themes and patterns in recorded conversations. The patterns may possibly be drawn from direct quotations and / or by summarising general thoughts of the participants. Based on the interpretation of the responses, brief comparisons were made between the four institutions selected for the study.

CASE STUDY OF EASTERN CAPE MUNICIPALITIES

Results and discussion

This section presents an analysis of the case study data. The section is comprised of quotations and other extracts from the interviews. To maintain the confidentiality of the participants, names of respondents have been deleted. In total, 10 respondents were interviewed. Two senior officials were interviewed at Ndlambe municipality, namely Deputy Director in charge of Community and Environmental Protection, and Infrastructure Project Manager. The case study at Makana Municipality involved three senior officials, namely, the Supply Chain Manager, Water and Sanitation Manager and Environmental Manager. At the Nelson NMBM, three respondents were interviewed including the Director of Supply Chain, Senior Conservation Officer, and Senior Environmental Officer. There were two senior officials that were interviewed at Sundays River Valley Municipality namely Director:
Infrastructure, and Project Management: Unit Manager.

Familiarity with the concept of green procurement

All the interviewees from both Ndlambe and Sundays River Valley Municipality indicated that they did not fully understand the concept of green procurement. However, the participants interviewed showed a big interest in green procurement. Interviewees at Makana Municipality expressed contrasting views. Two of the respondents were partially familiar with the concept of green procurement; nevertheless, one of the interviewees was familiar with green procurement. While some of the officials are passionate about protecting the environment, the municipality still works in insolation which then makes it very difficult to influence what other departments are doing. The majority of the interviewees across the case studies expressed serious concern that they had never included green procurement on their agenda and they do not view green procurement to be of significance. The NMBM, respondents stated that the municipality has started with the initial implementation of green procurement and senior officials are familiar with the concept.

Pre-qualification of designers and contractors in terms of environmental management practice

All the respondents across the case studies answered 'No', the interviewees supported this view by stating that they only use price and preference in awarding contracts. They have never included environmental management practice as an eligibility criterion in awarding

construction contracts. The critique towards not using environmental management practice as an eligibility criterion was attributed to the fact that green procurement is still at infancy stage and there are as yet no specific guidelines. However, respondents from Makana Municipality commented that in some smaller contracts that are carried out by the environmental department, environmental management is incorporated as part of the specifications. If the departments could share information, it could assist in raising environmental awareness.

Do you think vegetation loss and illegal dumping of construction waste could be curbed by green procurement?

All the respondents affirmed that vegetation loss and illegal dumping of construction waste could be curbed by green procurement. Several interviewees subsequently confirmed that the municipality is battling with illegally dumped construction waste. The interviewees attributed the problem of vegetation loss and illegal dumping of construction waste to the fact that the municipality is faced with other issues such as poverty, water shortage, infrastructure maintenance backlog, and budget shortages, which in turn results in green procurement being the least of the municipality's priorities. On the other hand, respondents from the NMBM stated that the municipality has tried to put policies in place; however, the rate of implementation has been slow.

Do you think there is enough emphasis on designing for the environment?

The respondents noted that due to all the challenges that the municipality is faced with, the environment is the least of their priorities. Respondents at Makana Municipality revealed that the environmental department is struggling to raise awareness among other departments due to environmental management being a low priority compared to all other challenges that the municipality is faced with. The situation is further exacerbated by the fact that this concept is still lacking momentum due to other pressing government priorities.

Do you think there is enough emphasis on environmental control and enforcement during construction?

All the interviewees stated that the municipality depends on national grants to implement infrastructure projects and if they do not spend the grant funding, the funds are returned to National Treasury, which reflects badly on the municipality. Therefore, during construction, the emphasis is on production rates and quality management, other issues are less important. One of the respondents noted that the environmental department is never invited to attend site meetings to assist in environmental control. All the participants shared the same opinion that environmental control and enforcement is not a high priority to the municipality. Although the EIA studies are carried out, the recommendations are not carried through into the contract documents, which in turn make it difficult for the municipality to enforce such recommendations. Respondents at the NMBM noted that the lack of regard to environmental control is attributed to a big lack of resources to implement environmental control and enforcement, although there is some level of control and enforcement, nonetheless more could be done.

Municipality's challenges in terms of environmental control

All the interviewees were of the opinion that lack of funds, personnel, and lack of policy or frameworks are some of the key challenges the municipality face in terms of environmental control. Respondents from Makana Municipality identified silo mentality on the part of officials as a barrier to environmental control and enforcement. Respondents at NMBM also revealed that supply chain policy silent on environmental issues is a major challenge hampering the environmental control and enforcement initiative at the NMBM. All the respondents across the case studies unanimously agreed that the lack of enforcement staff was the primary challenge and the fact that environmental issues are a low priority for the municipality it is very difficult to employ enough people.

Comparative analysis of the interviews

Most of the officials interviewed believe that green procurement is a fairly new concept in South Africa and it is yet to develop. A few believe that green procurement is reasonably well developed within the municipality however; government shows little interest in the subject.

With regard to pre-qualifying designers and contractors during the procurement process, interviewees across the case studies agreed that they have never included environmental management practice as an eligibility criterion in awarding construction contracts. The respondents stated that, they only use price and preference in awarding contracts. However, only one municipality reported that in some smaller contracts that are carried out by the environmental department, they incorporate environmental management in their specifications. Some of the respondents interviewed believe that if the departments could share information, it could assist in raising environmental awareness.

All the respondents interviewed believe that the implementation of green procurement could be used as an impetus to curb vegetation loss and illegal dumping of construction waste. Most of the respondents lamented that while the municipality knows about the problems in terms of vegetation loss and illegal dumping of construction waste, the municipality shows little interest, pointing to more pressing issues the municipality faces. Nevertheless, one of the municipalities has tried to put policies in place; yet the rate of implementation has been slow.

Pertaining to environmental control and enforcement during construction, participants across the case studies expressed the same sentiments that there is less emphasis on designing for the environment. All respondents unanimously agreed that there is lack of attention to environmental control and enforcement during construction. Rather attention is focused on production and quality management. Most respondents also believe that although Environmental Impact Assessment (EIA) studies are carried out, in contrast, the recommendations are not carried through in the contract documents. One of the respondents believes that this challenge is as a result of lack of resources to carry environmental control and enforcement at the municipalities. All the respondents also identified lack of personnel as the most dominant challenge.

Themes drawn from interviews

The following themes emerged from the case study interviews:

- Green procurement is still at infancy stage in South Africa, with the municipality and the government showing little interest in the subject;
- Environmental management practice is not an eligibility criterion for selecting/awarding construction contract;
- Rate of implementation of green procurement is lagging behind at municipality level;
- There is lack of environmental control and enforcement during construction;
- The lack of enforcement personnel is the most predominant challenge to the implementation of green procurement, and
- The key drivers of green procurement include vegetation loss and illegal dumping of construction waste.

CONCLUSION

This study investigated the implementation of green procurement as an instrument to curb the challenges of environmental degradation such as vegetation loss, illegal dumping of construction waste and climate change. It focused on four municipalities in the Eastern Cape Province. This is mainly because local government is the authority charged with the actual realisation of national policy relating to environmental sustenance.

The results of the study reveal that although green procurement concept is not a new concept, it is still at infancy stage in South Africa, with the local government showing little interest in the subject. It is also evident in this study that lack of funds, personnel and policy framework are considered the primary challenges to the implementation of green procurement at municipal level. Moreover, there is no clear driver (responsible department) as to who should drive the process of developing green procurement. Barriers such as costs attached to green procurement implementation in the construction sector are only perceptual. Instead, the reality that takes into account the entire lifecycle of construction projects bring these challenges to balance.

The study suggests that emphasis on policy and training may effectively advance green procurement in municipalities given it can be used to address past discriminatory policies and practices. South African initiatives that relate to green procurement such as eco-labelling are instrumental in facilitating the integration of green procurement.

The researcher hopes that this study will be a basis for innovative methods that will encourage environmentally friendly strategies in construction projects. The study provides room for further research particularly in the enforcement of the concept in day to day procurement practises. There is also a need for further research to determine the resulting impact of

implementation of green procurement in municipalities with specific focus in construction industry.

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BIM and Management

ILLUSTRATING HOW A SYSTEMS APPROACH TO MODELLING PROJECT PLANS IMPROVED INNOVATION IN OPERATIONS

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Keywords: Project Management; Planning; Plan optimisation; Modelling

Abstract:

Heathcote and Coates (2017) presented a quantitative study that showed how simple plan 'models' of planned operations could form an important precursor to innovation on projects. That study showed a statistically significant gain on modelled projects against the control group. Reporting on the findings of unstructured interviews with the intervention group project managers, from the 2017 study, this paper provides a more detailed explanation (and illustrations) of more precisely how those improvements were made. Some techniques represent the effective use of computer aided planning tools, with an important emphasis on 'modelling for analysis' rather than traditional 'planning'. Other techniques include methods that can be generalised to 'lean management' and/or 'supply chain management' approaches. Such improvements can form transferable learning to other projects. Two hypotheses are proposed, that H1 "systems' analysis can be supported by visualisation through Gantt chart type modelling of the planned operation". And that: H2 "the management of projects, can be supported by the adoption of supply chain/operations management principles".

INTRODUCTION.

Project management is closely associated with planning (Morris 1997, Dvir et al 2003, Gardiner 2005, Maylor 2010). Several authors point to the importance of logic linked tasks, and the identification of the 'critical path' (Tasks that do not have float time), within plans as a method for more accurately reviewing the possible impact and risk arising from inter-task schedule dependencies (Morris 1997, Dvir et al 2003). Morris (1997) shows how CPM (Critical Path Analysis) becomes firmly associated with the management of project schedules in the late 1950s and 1960s. A review of contemporary texts on Project Management confirms its continuing prevalence. (Gardiner 2005, Maylor 2010). However there is some evidence (Soderlund and Geraldi 2012) that the technical difficulty of putting the plan together in the software, coupled with the changing nature of the planned schedule as the project is implemented (necessitating frequent revisions), leads to the planschedule becoming less important and more redundant as the project progresses into delivery (Soderlund and Geraldi 2012).

Ajani (2002) details a planning method that appears to combine CPM, PERT (Planning Evaluation Review Technique) and a concern for the project outcome into a single planning focussed approach he called 'Extreme project management'. This approach might be

interpreted as simply combining CPM with Supply Chain Management (or 'Operations Management') that arose in approaches to improve the flow and efficiency of work in manufacturing and has been detailed by Goldratt (2004) and termed 'Theory of Constraints' (Cox and Schleier 2010). Here Goldratt (2004) shows how stepped improvements to workflow can be achieved by identifying the 'bottlenecks' in the system of the operation, and widening the bottlenecks to improve the operational work flow. Goldratt (1997) goes on to show how this thinking can be readily applied to projects as well as manufacturing, though it can be noted that the examples of customised manufacturing he uses might be also considered to be projects. Christopher (1998) and Porter (1985) both examined 'supply chains', their: 'inbound logistics'; 'operation' and 'procurement' to consider how the efficiency of that work might be enhanced in terms of both speed and cost of delivery. These sources show how interlinked planning approaches to the management of projects are described within both 'operations management' and 'supply chain management' philosophies. Arguably project management borrows from the management philosophy of operations/supply chain management when it describes the optimisation of the scheduled plan.

For the 2017 SEEDS conference Coates and Heathcote (2017) presented a study that was able to examine the efficacy of projects that did exploit schedule plan models when compared to a control group. Their paper involved a quantitative unpaired study that compared an intervention group of 'systems' planned projects against a control group of projects that were not planned in a coordinated pure logic and visually well communicated way, the SEEDS 2017 paper (Coates and Heathcote 2017) found that:

> Hypothesis 2: Consideration of the planning principles of WBs and logic linked critical path modelling facilitated be er management of the projects, resul ng in a measurable improvement, in Adjusted Gross Margin over the sample examined. Adjusted Gross Margin was the Gross margin when compared to the forecasted expectation of the projects performance at the time of bid offer/win. This is a more testing measure of success for the sample. This was found to be correct and statistically significant (P = < 0.05) and is illustrated in figure 1 below.

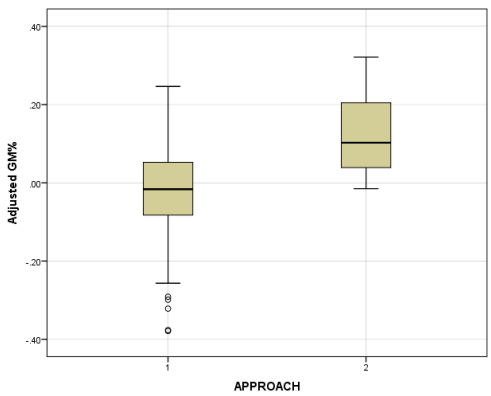

Figure 1. Invention group 2 outperforms the control group 1 to deliver projects that make more profit margin.

Hypothesis 3: Consideration of the planning principles of WBs and logic linked critical path modelling facilitated better management of the projects, resulting in a measurable improvement, in timescale, (when compared to the forecasted schedule for comple on at tender bid win), over the sample examined . This was found to be correct and statistically significant (P = < 0.05) and is illustrated in figure 2 Below.

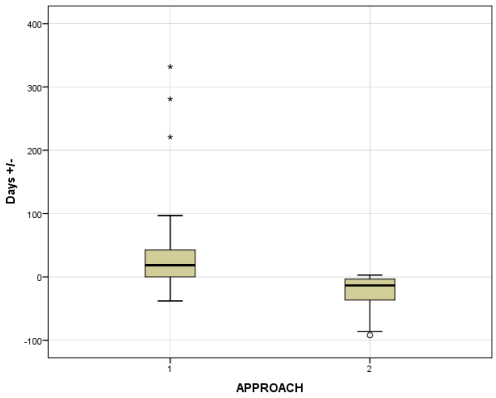

Figure 2. Invention group 2 outperforms the control group 1 to deliver projects faster.

This study might be important, because it was able to quantifiably measure a notable improvement in performance from those invention projects that did use project planning and critical path analysis, and the control group, which did not. The overall performance of projects in the invention group, in terms of time and gross margin, was statistically significant in outperforming those in the control group.

In conclusion Coates and Heathcote (2017) raised some further questions that might more fully examine the findings.

The initial Coates and Heathcote (2017) work raised questions about a number of possible confounding extraneous variables.

Coates and Heathcote (2017) specifically recommended that;

> *" Some further wor needs to be carried out to understand more specifically how the systems orientated pro ect managers in the sample (generally these are the last two years) are utilising better planning coordina on to enhance their projects performance.*
>
> *The improved performance between the invention sample and the control group is notable and understanding more precisely how this was achieved might be of benefit in illustrating what good practice project planning might involve".* (Coates and Heathcote 2017).

To address this issue raised in Coates and Heathcote (2017) this study asks the research question:

"What methods did project managers, in the case study, use to achieve better project performance?"

To achieve this illustration, qualitative interviews with project managers from the intervention group were undertaken.

RESEARCH REVIEW AND METHODOLOGY

Qualitative interviews were undertaken with the intervention group project managers at the case study organisation in Coates and Heathcote (2017). Several writers point to the value of qualitative research work in providing a richer depth of explanation and understanding of observable and measurable phenomena. (Parahoo, 1997. Saunders et al, 1997. Symon and Cassell, 1998. Polit and Beck 2012). Symon and Cassell (1998) set out a foundation argument for the rise of post-positivist approaches that allow for the generation of new theory, and question whether theory grounded (solely) in data is sufficient to allow for the development of our understanding of a filed or of phenomena. Gabriel (1991a) cited in Symon and Cassell, 1998 identifies the usefulness of 'stories' and story-telling in the development of new theory. This seems apposite to this study as the hard project performance data from the antecedent paper formed the context and prompt start point for open question interviews that solicited both direct explanations and 'contextual stories' for the interviewees.

The interviews were planned to be qualitative in nature, inviting a reflection in the respondents, and accepted the limitations of the subjective component of the results in order to attain data that can meaningfully help the researcher. In this case, qualitative interviews sought to identify possible causes of the observed improvement to develop a more nuanced insight into the methods adopted (Parahoo 1997). Accepting the limitation that this might lead to more subjective responses (Polit and Beck 1998, Symon and Cassell 1998) the method allows for the development of hypotheses to explain what other causes might be a work.
The previous proven hypotheses are necessarily narrow in nature (to allow testing) and can be better understood through examining the detail of how project managers understood the interventions they made, in what is assumed to be, a result of more complex coordination.
The interviews were semi-structured, involved A3 planned Gantt examples as artefacts to refer to, and involved open questions that sought help to identify what specific changes had the intervention group of project managers made to create the performance their projects enjoyed. Open questions are designed to nudge the respondent (Symon and Cassell 1998, Parahoo 1997, Saunders et al 1997) to solicit a free flow of information from the respondents and not steer them, so to allow for topics of importance to the respondents' perspectives to be raised (Symon and Cassell 1998).

Interview Findings

In general, the respondents were aware that their projects routinely outperformed the average performance of the 'control' group projects.

During the interviews, the respondents did further explain their answers by referencing examples from recent projects.

1. In general, the intervention group described their approach as being preceded by the building of the project plans.
   1.1. The primary method of improving performance involved changes **rejected in-house services and outsourced those services to specialist suppliers**,
      1.1.1. Asked whether this brought about cost and time advantage, the respondents agreed
         1.1.1.1. But added that it was achieving '**actual control'** that was the key issue.
2. ' Actual control' over the project, had been rendered difficult, because of
   2.1. 'the internal management system'
      2.1.1. And through the internal management structure which at its worst could establish a 'Chinese whisper' that led to politics as in-between parties sought to justify their performance through 'story telling' and limiting communication access.
3. i.e. *this was illustrated by some in-house built control that included 12 errors in a subcomponent that was ready to ship. The changes were spotted and shipping was delayed, as changes were made, incurring a 5% cost uplift that needed to absorbed by the company.*
   3.1. Stories were told to **transfer the blame**, to other departments, and serves to **make the problem less visible**.
      3.1.1. When escalated to the executive level senior management sought to bring worker relationship harmony and **did not see the consequences** of additional time and costs. This was evident at a subsequent fortnightly reporting cycle, when the managers asked why that project was experiencing cost and time overruns.
         3.1.1.1. This seems to indicate that there was no 'system' perspective amongst management.
4. 'Storytelling' to excuse time and cost overruns was normal, and the respondents felt that there were not enough 'stringent' processes to allow for smooth running of the projects.
   4.1. The interviewed intervention team said in-house teams would often '**go-technical'** meaning they would present complexity technical reasons for none performance.

5. In contrast these in-company problems were **avoided using by outsourced suppliers**
   5.1. i.e. *When a problem arose because of an overlooked design detail, this error (requiring additional work) was absorbed by the sub-contractor who was doing the work at risk. Where the in-house installer doing the work, then the work would be internally charged to the project.*

6. The interviewed intervention team thought that **outsourced contractors tended to**

6.1. be **less cost**,

6.2. but also those costs were **more predictable**.

6.3. i.e. *It was discovered that often specialist sub-contractors could buy parts at less cost because they enjoyed a greater bulk discount of specific items. Comparing those prices to the case study company's prices allowed verification of this.*

6.3.1. As well as greater discounts suppliers enjoyed better service from their parts suppliers.

6.3.1.1. Getting sub-contractors to buy their own equipment and parts, even when specified by the case organisation, led to lower costs and

6.3.1.2. The advantage of improved coordination, as the sub-contractor was able to both order and organise delivery to suit their own programme. **This reduced a coordination interface**.

7. The **coordination of work on-site**, was a particular challenge. The intervention team made a small number of changes to address this problem.

7.1. Changes that had to be accommodated at site installation, were difficult, added time and were costly.

7.1.1. The intervention team, tended **to introduce their various sub-contractors to one another**, allowing for site coordination of works, without *post boxing* back and forth via themselves, thus having the effect of removing a communication barrier. Others were wary of this, because they felt it last some control, however the intervention team thought it mostly beneficial. They were in the habit of cc'ing in other sub-contractors that might have an affected interface.

7.1.1.1. Previously this might have involved a series of internal departments who were not obliged to accommodate one another.

7.1.1.1.1. This internal coordination problem was avoided by the management team, who saw conflict as human resource issues and simply sought to de-escalate without addressing the coordination problems. Consequently the **problem was never acknowledged or recognised.**

7.1.1.1.1.1. Two weekly reporting cycles meant that project non-performance identified the consequences of the conflicts but **senior management each time seemed unaware** of why these were repeating issues, or their part in perpetuating them. 7.1.2. To help improved site coordination further the intervention team included **standard design templates** for items such as base plates and connecting hoses.

7.1.2.1. This increased initial costs but these were rapidly overcome by the **improved flexibility** that allowed for interface issues, between separately supplied kit, to be fixed.

7.1.3. The intervention team noticed that sub-contractors tended to point out their errors to them, being available to this criticism meant that they effectively received:

7.1.3.1. ..design checks for free!

7.1.3.2. ..they were also receiving 'free' ordering service as that part of the equipment purchase was left to the sub-contractors,

7.1.3.3. This ordering also meant that any parts' damage was at the subcontractors' risk, so they tended to resolve it quickly.

7.1.3.4. 'Shipping' was a part of the project that the intervention team retained from the in-house service, because "We are good at that".

8. The Gantt Chart plan, provided the 'spark' for these changes, helping spot the problems, and understand what was possible. Had we not had that improved model of possibilities we might not have pushed through the improvements. So it helped to be certain and committed to the fact that what we were changing would work.

8.1. At the 'case organisation' the project managers are not really 'project managers' instead they are sort of **co-ordinating expeditors**. The interviewed intervention team felt they had moved from this to a proactive control that allowed for known problems to be identified properly and removed through considered off-line planning, and a willingness to challenge the established way of doing things.

8.2. Generally the company still makes these mistakes,

8.3. The intervention team, tended to be allocated to more and to critical projects, as the more they undertook, then the better the overall company performance.

8.4. The intervention team feel they are better at identifying problems (because they could see them, due to the plan model) in other team's projects and sometimes get called upon to 'help'. This involves, not replacing as project manager, but adding one were they previously might not have been one.

8.4.1. It should be noted that often the job was led by a design engineer, who would have a focus on technical design rather than plan coordination.

8.4.2. Where PMs did exist (outside of the invention group) their role was accepted to be about reactive monitoring and reporting rather than proactive coordination.

8.4.3. i.e. *"I could see on this large job that the costs of a particular task were not factored in, as there had been an assumption that another department was doing the work. It led to a significant cost increase to accommodate these unforeseen costs."*

9. In the branch of the group that the intervention group sat in, the improvements by this team led to the dissolution of some of the in-house departments.

9.1. Outsourcing was an easier immediate solution rather than addressing the uncooperative process and culture.

9.2. Other advantages were that overheads are reduced and productivity is climbing.

DISCUSSION AND CONCLUSIONS

The interviews reveal a number of 'system' issues that the project managers in the case organisation's sample group were experiencing. As Morris et al (2010) predicts much of the issues underpinning the improvements were the PMs simply addressing the 'waste' in the existing organisational way of doing things/operation. Point 7.1.1.1.1.1. is interesting because it demonstrates that management had less of a strategic overview than the project teams themselves, a point also referred in 3.1.1.1. The interviewees primarily attributed their improvements in the operation to the 'outsourcing' of some in-house services, were they could receive more attentive consideration for their project, and were they could use improved timings to reduce overall project costs (even thought this sometimes meant the the costs of the parcels of work were increased). This led to what they termed 'actual control' and this was a precursor to pro-active management of the project. This raises some questions about how cooperative internal departments in modernist organisations are. Items 1 – 5 deal with this issue, and it was plain that the consequential effects of the difficulties of coordination (aside from being measurably poor performing, Coates and Heathcote 2017), were the source of negative political tension inside the organisation. It is clear that much organisational effort goes into allocating blame for poor performance, even before project failure occurs. It would be interesting to see how widespread this behaviour is in the management of projects. Item 6 deals with the advantages that arose from being able to rationalise communication across team members. The respondents show how this often involved introducing suppliers to one another. They effectively flattened the structure of communications and avoided becoming 'just a post-box' between project team members.
Quality was improved as interfaces were less, but also that suppliers were directly responsible for any mistakes in interfacing they might make. This is interesting because the interviewees thought that (in the control group), PM was much more of an expediting role, and as such runs directly contradictory to the principles of 'supply chain management' which would seek to avoid this. Section 7 also demonstrates how the visibility of the interface issues could be anticipated and designed out. Knowledge of known risks were transferred to other projects and permanent solutions created.

8.4.2 Might be critical to the way project management is conceived. The case organisation's control group perhaps shows how project management is sometimes perceived as a coordinating, reporting and monitoring in a relatively passive way, and also when intervention is required, as an expediting role. The invention group of PMs were acting very differently from their peers by being pro-active in mitigating known risks and creating solutions in the form of templates and design changes, and also in delegating interface responsibilities to their 'partners' in the sub-contracted suppliers. Arguably the visualisation of the Gantt chart info-graphic, and their ability to 'model' the project plan complexity and interdependencies, facilitated this change in approach. What might be an important demonstrator of this is how the interviewees were able to use their 'mental map' of the project to stop errors of omission in projects in the control group. (8.4.3).

Item 9 shows that some changes had been made in one company in the three company group. This may represent a reactive approach, rather than a wider examination of the coordination issue. The organisation may have been able to perform better overall had the advantages of the sub-contracted suppliers been created in the in-house departments. At this theoretically

this should be possible and it is not difficult to imagine how that might lead to a synergistic advantage were improved coordination to be achieved. What is surprising, perhaps, is that organisations such as the case study find it so difficult to achieve cross departmental cooperation. In changing to a culture of continuous and cooperative improvement, avoiding 'blame' seems a precursor to any development in that direction. Arguably, the intervention groups' performance should be able to be mimicked across the team where that team uses the same principles to achieve what was possible with a contracted-in set of suppliers.

CONCLUSIONS

As Soderlund and Geraldi (2012) showed Gantt charts can be effective when the teams consider them worth it, and here the invention group utilised the plan model for analysis. Taking this approach of 'modelling for analysis' seems key to how the team was able to improve their projects' performance when compared to the control group. Critical to this was the ability (and willingness) to be able to analyse the detail of the problem impacts in the operation. Consequently this allowed for the designing out of future interface challenges, detailed in section 7. This approach included designing key solutions for flexibility for site operations. It also led to the standardisation of some design templates to reduce the complexity of site based interfacing of sub-packages of kit that might otherwise cause delay as customised retrofit solutions would have to be found. Arguably the 'model' empowered the project team to make decisions to outsource key work packages rather than pursue the 'authorised' use of the nominated internal departments that had typically carried out this work. The challenging nature of this 'move' is not evident in the interviews, though some reference to the resolution of issues by senior management is made in 3.1.1. The interviewees appear to come to the realisation that senior management had no complete overview perspective of the impacts of operations on the projects, and so reporting became about 'explaining' to senior management what was happening. This also provided the invention team with some freedom for autonomous decision making. In the interventions teams' wake was an organisation they characterised as in-fighting and effectively created a temporary organisation for each project, increasingly disconnecting themselves from the internal operation, in favour of one constructed from trusted suppliers.

To achieve this; principles were employed that exist in supply chain management, (and arguably total quality management's) principles of autonomy and attending responsibility for actions and in this case seamless interfacing. The success of the intervention group contrasts a 'supply chain' interpretation of PM with one of PMs as post-box coordinators of in-house services and reactive expeditors. This challenges the contemporary development of project management and suggests that some consideration for the assimilated principles of Supply chain management and total quality management ought to be re-emphasised.

The intervention group interviewed did use the Gantt chart project plan to model the project delivery, but it seems important to note that this merely served to: prompt the challenging of the existing ways of doing things; identify constraints as a problem identification prior to removing them; create strategic perspective; allow for the visualisation of what was possible; model the potential of solutions; justify action and empower the team. Claiming that the Gantt chart model did this on its own would be wrong. The interview based research allows for the formulation of new theory; that H1 *"systems' analysis can be supported by*

visualisation through Gantt chart type modelling of the planned operation". And that: H2 *"the management of projects, can be supported by the adoption of supply chain/operations management principles".*

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FACTORS MOTIVATING THE ADOPTION OF BIM- BASED SUSTAINABILITY ANALYSIS

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Key words: BIM technolo gies, BIM based sustainability, Environmental Assessment methods, Sustainability drivers and barriers.

Abstract

The delivery of sustainable and green certified buildings such as BREEAM and LEED is a highly discussed topic with significant interest growth between the Architecture Engineering and Construction (AEC) industry. At the same time, professionals in the AEC have started to recognize the importance of the synergy between Building Information Modelling (BIM) and the assessment of green building strategies to the construction industry. Several studies demonstrated BIM as a platform for collaboration in the AEC sector in general, rather than to deliver green buildings. Thus fewer researchers have tended to investigate the external and internal problems/factors that affects the delivery of green buildings, and role of digital tools and BIM based strategy in solving them. Through thematic coding of existing literature, this paper formulates a critical review of the key drivers for the change needed in AEC industry. It maps knowledge, makes recommendations for improved collaboration, and offers general insight into the delivery of green building design. This review will act as a base to address the critical factors affecting the delivery of green buildings, and investigate how integrating BIM with sustainability aspects could overcome workflow problems towards better collaboration. The investigation concluded that the practice adoption to BIM-based applications is affected by the immature level of integration and lack of consistent framework that is based on the problems in the workflow, process and gap in communication strategies captured from the field work.

INTRODUCTION

The Construction sector is criticised as an industry that consumes 40% of global energy consumption and waste generation, and 25% of the global water consumption (Balasubramanian and Shukla, 2017b). This had created a global interest towards delivering green buildings, which in turn had highly influenced a change of altitude of the AEC industry (Ahn *et al.*, 2013). A significant number of studies has reported problems facing a project team in delivering green buildings, which has consequently led to an increase in extra costs and time of the project (Hope and Alwan, 2012; Alwan, Greenwood and Gledson, 2015a). At the same time, BIM was identified as the reason for a paradigm shift in the AEC industry,(Taylor and Bernstein, 2009). This has developed a revolution in ways of visualizing, analysing, sharing and documenting project data amongst project teams (Ghaffarianhoseini *et al.*, 2016).

In addition, several studies have discussed problems associated with traditional project delivery and have pointed out the potential that the integration of BIM technologies and sustainability design have to enhance productivity and improve efficiency. This applies to all project stages; from briefing and design, though to construction and project operation and maintenance. (Azhar and Brown, 2009a; Stapleton, Gledson and Alwan, 2014a; Ghaffarianhoseini *et al.*, 2016; Hamada *et al.*, 2016). Also, the academics and experts in the field started to recognize the importance of the synergy between (BIM) and the assessment of green building strategies to the construction industry. In spite of, the growing BIM interest, it is observed that in practice most applications in the industry and BIM promoting events are concentrated more on the 4D and 5D applications – time and cost, with limited concern about incorporating sustainability within BIM approaches. Therefore, the purpose of this paper is to understand the reasons behind the evolution in research regarding BIM and sustainability, which created a need for bridging BIM practices and sustainability.

Most of the studies discussed the drivers and barriers of the two poles of the change in the AEC industry; BIM and green practices, by demonstrating them individually. In order to conclude what are the reasons behind the need for adoption of BIM based sustainability, as shown in Fig. 1; the evolution of the significance of its' adoption needs to be investigated. A comprehensive thematic literature was developed to identify a deeper insight into the research gaps and act as base for areas that need investigation. In addition, the paper will access the drivers for adopting BIM and sustainability approaches as catalysts for change in the industry. Finally, it will demonstrate how some barriers to delivering green buildings with the help of the potentials of BIM impact the recognition of the synergy benefits.

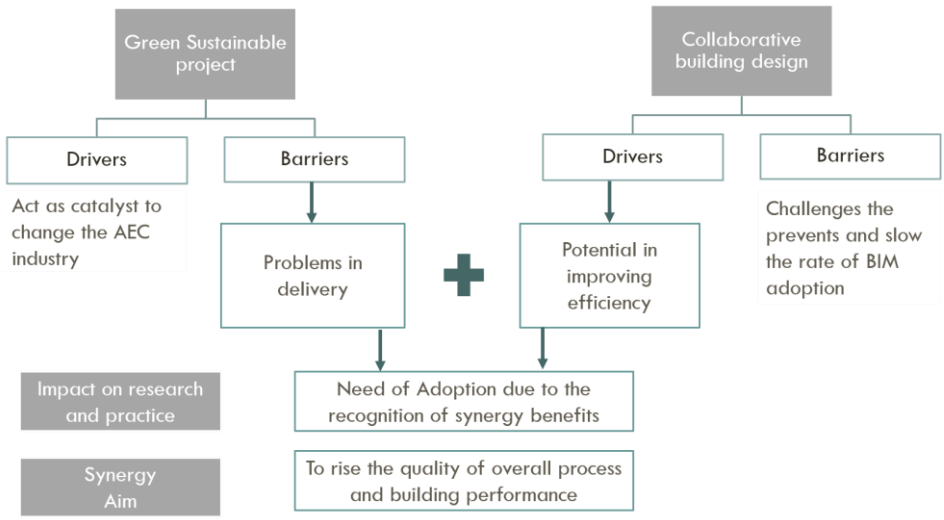

Figure 1. The evolution of Research Significance

RESEARCH METHOD

This section will explain the research method, which will include the criteria of the selection of papers, how they are collected and analysed. This paper formulates a critical review of existing

literature through thematic coding of the key drivers affecting the change in the industry towards BIM-based sustainability, as mentioned above. According, to the discussed motivators in the introduction shown in Fig 1, the first step was to identify the different themes mentioned in table 1. Those themes aim is to address the contribution of the synergy through understanding of the reasons behind the evolution of the benefits and challenges of the new strategies adoption. Google scholar and Scopus were used as search engines to collect relevant peer reviewed journal and conference proceedings papers that are directly related to the titles using the key works in table 1. After filtering, a total of 38 peer reviewed papers were used for the four themes to be able to categorize factors and areas of development. The third step was to draw the effect of the reviewed literature to point out its current contribution and gap of knowledge that require further work.

Table 1 Main themes and the used search keywords

Main Themes	Main key words	Search key words
Driving forces to deliver sustainable buildings	Green buildings deliver, sustainable buildings, sustainable design and construction, green certified buildings , Environmental assessment methods (EAM), rating schemes/tools	+ Driving forces, Motivators, demand factors, influencing adoption, promotion strategies, perceived benefits, incentives
Barriers of sustainable building delivery		+ Barriers of adoption, barriers of delivery, risks, factors, obstacles
Driving Forces for Collaborative Building Design Adoption	Green BIM, BIM based sustainability, collaborative design, Green practices in BIM	Applications , promote BIM , synergy benefits, integration, impact , potential , development
Barriers of BIMbased sustainability		Problems, obstacles, challenges, barriers

LITERATURE REVIEW

Understanding the evolution of the perceived benefits and the challenges of the synergy between the BIM and green practices is important to be able to point out the current contribution of BIM in delivering sustainable projects. The academic literature on both BIM and sustainable project delivery has revealed the emergence of several contrasting themes. This section will discuss and present a series of categorized factors studied in previous research on the driving forces and barriers for adopting BIM and sustainable building approach.

Driving forces to deliver sustainable buildings

Numerous studies have been published on the driving forces to deliver sustainable projects (Olubunmi, Bo Xia and Skitmore, 2016; Darko *et al.*, 2017).These studies reported and

evaluated the AEC driving forces towards green construction practices. Some of those driving forces were also applied on the increase in demand of the certified buildings using Environmental assessment methodologies such as LEED and BREEAM. Figure 2 represents the common categories found in 6 papers that discussed and evaluated the importance of the driving forces in the AEC industry. The approaches to group those driving forces were different. For example (Balasubramanian and Shukla, 2017a) drew attention to the driving forces of green implementation and divided them into internal and external driving forces with respect to the organizations stakeholders which was developed through the literature review. Darko et al. (Darko, Zhang and Chan, 2017) grouped the drivers into corporate level, external, property-level, individual level and project level, and a survey using quantitative analysis were conducted to rate the effectiveness of those factors on the AEC industry. Ahn et al. in 2013 (Ahn *et al.*, 2013)**,** clustered the driving forces into 3 : economic, environmental, and social, but more factors were investigated and categorized; such as global and governmental pressure (Olubunmi, Bo Xia and Skitmore, 2016; Shazmin *et al.*, 2017).

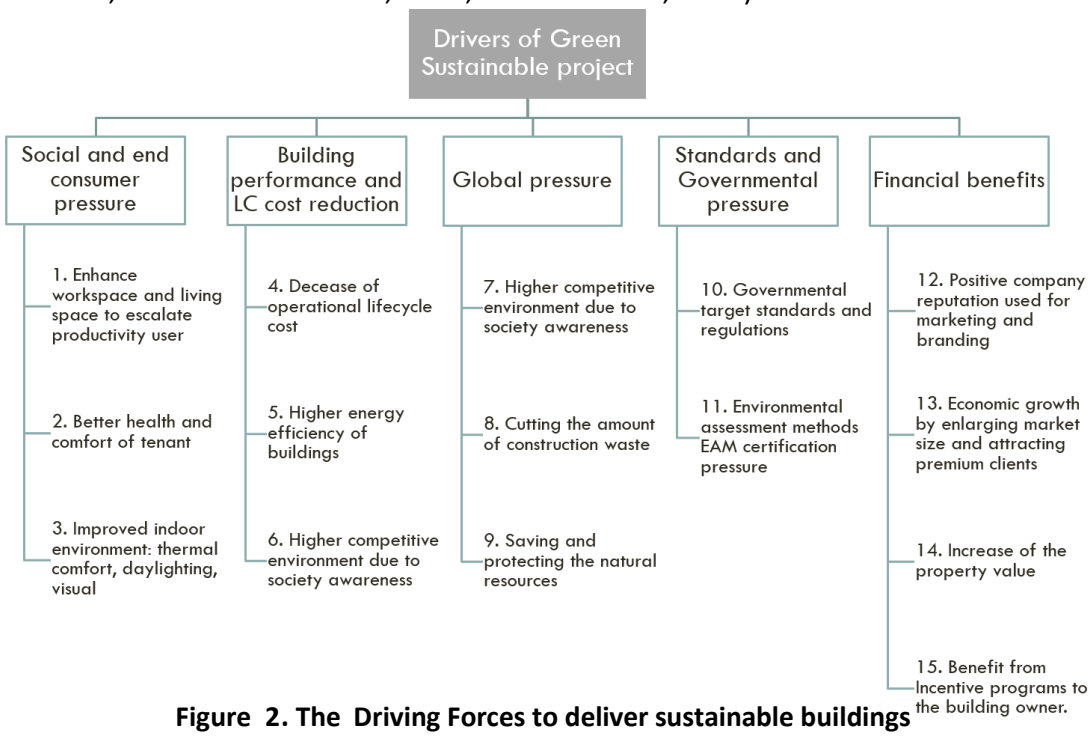

Figure 2. The Driving Forces to deliver sustainable buildings

The choice of the listed factors was according to the most common factors discussed among recent studies. Using different approaches such as Literature, empirical studies and quantitative analysis, the researchers were able to investigate the factors influencing the change towards green implementations in the AEC sector. However, limited studies focused on those driving forces as catalyst of change in AEC industry in the direction to BIM- based sustainability adoption. Fifteen driving forces are listed in Figure 2 under five categories: social and end consumer pressure, building performance and LC reduction, standard and governmental pressure, financial benefits to the owner and user of the property.

Barriers of sustainable building delivery

To be able to access the contribution of BIM in green project delivery, it is crucial to be aware of the barriers of green construction practices. It is important to know the obstacles that affects the increase in the green practices adoption, to be able to then evaluate the level of contribution of the synergy between BIM and sustainable design. The benefit of investigating the previous research discussed the barriers, that the researcher will be able to determine the areas of improvements to overcome some barriers and at the same time avoid claiming that the integration will solve all problems in the industry towards green practices. Figure 3, presents an overview on the themes investigated before in previous studies on the barriers of green project deliver. The existing literature of the barriers for delivering sustainable building has focused more on the current industry deficiency, risk of investments and initial costs and also of the rigidity of change in practices. Numerous research have attempted to explain the influence of those obstacles on the adoption of green strategies. However, a systematic understanding of how BIM based practices contributes into the reduction of the influence of some barriers is still lacking, especially on the effect of reducing cost by using BIM technologies on the long run.

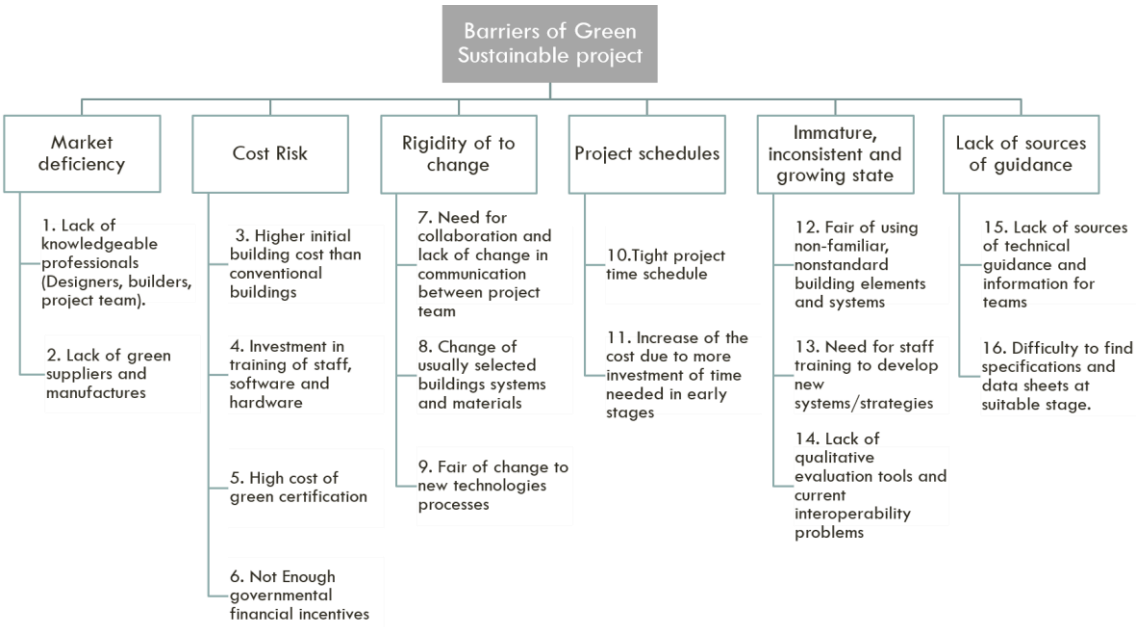

Figure 3. Barriers to deliver sustainable buildings

Balasubramani (2017), demonstrated the relation between the drivers and barriers of green practices to the development needed with respect to stakeholders in the industry in core building practices and facilitating green practices. Also, recommendations were proposed in different studies to overcome barriers by promoting the benefits of developed markets (Wimala, Akmalah and Sururi, 2016; Nguyen *et al.*, 2017). For the literature, researchers agreed that it is essential to focus improvements on different tracks to overcome green building (GB) barriers. As mentioned in Hopkins published paper in 2016, it was argued that : altering perspectives of practices, targeting development of universities education, changing policies, finding ways of funding for GB financial incentives are possible solutions. In addition, improving

ways of GB delivery to overcome processes efficiency in terms of extra cost and time could be a motivation for stakeholders to adopt GB practices.

Growth of BIM use in AEC

Another significant observation in the last decade, highlighted by many studies, is the growth of adopting BIM technologies.(Tulubas Gokuc and Arditi, 2017) BIM is promoted as set of policies, technologies and process that allows project team to work in proactive decision making environment (Razkenari, Nanehkaran and Barati, 2016). The main driver of the practice growth and significant research interest is the paradigm shift that BIM technologies offer in ways of visualizing, organizing, analysing, simulating building performance and documenting project information. The fundamental strategy to ensure collaboration within BIM process is to have centralized, defined, structured, and easy exchanging data environment. This strategy is still in process of developing to enhance the work efficiency of the construction sector that is suffering from fragmentation of work, multi participants' process, increasing complexity and use of variety of systems and technologies. However, consistent framework with respect to sustainability application has not been established yet.

Driving Forces for Collaborative Building Design Adoption

The main driver pressuring the need for change in AEC industry, is the criticism on the significant amount of waste in project life cycle. (Saad Sarhan and Christine Pasquire and Andrew King, 2017) This waste could be physical, such as waste of materials or primary waste for example waste of time and effort in rework, disputes and delays. It is also blamed for the slow progression over the last 60 years in terms of efficiency(Saad Sarhan and Christine Pasquire and Andrew King, 2017). Therefore, research and practice are driven by the idea of increasing the value for all stakeholders with less effort, time and cost, it is proved that collaboration is the key to achieve this aim. (Venkataraman and Cheng, 2014)BIM capabilities enable effective collaboration between different disciplines, but at the same time unsatisfactory percentage of the use of BIM in sustainable projects within practice is reported in recent studies. BIM revolutionary technology and processes are explored in multiple of studies towards creating harmony among project team. (Azhar and Brown, 2009b) Zanni, Soetanto, & Ruikar, 2017) Different tracks of development to support the potential of BIM were attempt to be addressed in order to enhance efficiency in workflow as shown in Table2.

Multiple studies in the last 10 years discussed the problems in traditional methods for green project delivery and pointed out potentials of the synergy with BIM (Hope and Alwan, 2012; Alwan, Greenwood and Gledson, 2015b; Luo and Wu, 2015). Accordingly, authors in the field focused on different development areas to benefit from the potentials of the synergy. The work of the leading authors in the field could be clustered into studies that focus on:

1) Tools capabilities in Modeling, simulation, visualization and automation.
2) BIM and Sustainability Framework and Management.
3) Enhancing information management and decision support for EAM.

It could be claimed that the above themes were evolved from the trending approach in the use of BIM which is reducing manual inputs and effort of work by developing automotive ways of producing information outputs from models. Also, utilizing BIM approach of having a structured, well-coordinated process with assigned responsibilities with manageable framework is important approach. Studies recently addressed benefiting from BIM model in its parametric state by developing scripts to automate variety of outputs such as quantities' and link them to the cost estimate (Choi, Kim and Kim, 2015). Using similar concept of automating outputs from the green building assessment models were developed in more than one study. These studies explored the utilization of BIM models to automate the estimated achieved EAM credits (Wu and Issa, 2012; Jalaei and Jrade, 2015; Ilhan, Bahriye, 2016). Other studies such as Lim in 2015, (Lim *et al.*, 2015) published study that attempted to map the sustainable design strategies with required the level of development (LOI and LOD)of the BIM model for effective integrated process driven design based on performance.
It can be observed that similar studies that are trying to map the level of detail (LOD) and Level of information (LOI) are very limited. It can be concluded that the literature shows more focus on development of software and tools, rather than process and workflow.

Table 2 Topics discussed by leading authors

Theme	Discussed topics	References
1. Focus on Software Tools capabilities in Modeling, simulation, visualization and automation	Simulation of building environmental performance- Energy, carbon, daylighting, LCA	(Wang *et al.*, 2017) (Stapleton, Gledson and Alwan, 2014b) (Ajayi *et al.*, 2015)
	Parametric properties and use of model for generation of automated outputs related to credit calculations.	(Wu and Issa, 2012) (Ilhan, Bahriye, 2016) (Jalaei and Jrade, 2015) (Han *et al.*, 2017)
	Reporting problems in Interoperability and proposing solutions	(Wong and Fan, 2013) (Moon *et al.*, 2011) (Lim, 2015) (Lu *et al.*, 2017)
2. BIM and Sustainability Framework and Management	Use of BIM-based sustainability analysis in different stages	(Wong and Zhou, 2015) (Lu *et al.*, 2017)
	Level of definition with respect to sustainability check points workflow	(Lim *et al.*, 2015)
	Input for BIM execution plan and responsibility matrix: Responsibilities, roles and deliverables	(Azhar and Brown, 2009b) (Gerrish, 2013) (Zanni, Soetanto and Ruikar, 2017)
3. BIM for Green	Process mapping and integration of BIM work and work needed to achieve credits	(Wu and Issa, 2013)

Certification Enhancing information management for green certification	BIM contribution in EAM delivery-assessment of use of BIM to achieve EAM credits	(Wong and Kuan, 2014) (Salman Azhar *et al.*, 2011) (Alwan, Greenwood and Gledson, 2015b)
	Common data environment and digital plan of work relation to EAM	(Ayman, Alwan and Marzouk, 2017) (Harding *et al.*, 2014)

Unfortunately, although the high potential explored in different directions of development in research, a gap is found in application in practice. Limited studies have found on developing execution plan of BIM- based sustainability that was based on the problems and deficiencies in workflow captured from industry practices.

Barriers of BIM-based sustainability

Despite the great potential and benefits mentioned above, unsatisfactory levels of adoption is observed due to the practice barriers.(Olawumi and Chan, 2018) It is recognized that common barriers are found in literature between BIM and sustainability implantation, which is related that they are both new changes in practices in the industry, shown in fig. 4. Previous research reported the same factors as mentioned of sustainability barriers, BIM adoptions obstacles in the market are the lack of skilled professionals, risk of initial investment, rigidity to change, lack of inconsistent framework that is derived from the growing immature state (Oduyemi, Okoroh and Fajana, 2017). On the other hand, some barriers; which are considered problems facing project team in delivering sustainable buildings, are demonstrated to be overcame with the potential utilization on BIM. Researchers claim that by adopting BIM based sustainability project design, construction and operational cost can be reduced as well as saving effort and time, by improving the work efficiency. This is achieved through the capabilities of tools and processes to eliminate conflicts, reduce rework, avoiding errors and omissions through visualization, coordination and structured framework. On the other hand, one of the main factors that benefits of BIM affect the initial productivity of the staff, due to time spent on learning process and discovering the problems in applying new approaches in work. Also, there is a significant influence between the relation of the client demands, satisfaction of the existence service and competition level among the professionals industry. (Eadie *et al.*, 2013) Some studies claim that this relationship on competition in market and non-satisfying service of traditional project delivery are influencing the rise of client demand to apply BIM within integrated project delivery. (Arunkumar, Suveetha and Ramesh, 2018a). But at the same time still the Immature and inconsistent framework for applying sustainability aspects within BIM protocols responsibilities, roles and deliverables, in addition to the lack of rational mechanism for checkpoints through project lifecycle are considered the main organizational obstacles (Zhao *et al.*, 2017).

The listed barriers are the most common, repeated in the review papers that evaluated their influence on the adoption of BIM in the industry, which will directly affect BIM based sustainability as well, as shown in Figure 4. Additional to the barriers of BIM based sustainability which is common to BIM, other internal barriers are only related to BIM based

sustainability. In Figure 4, the additional barriers are categorized under technological, legal and extra initial cost. One of the highlighted barriers are the level of accuracy of the simulation of the energy and building performance tool and risk of reliability on them (Arunkumar, Suveetha and Ramesh, 2018b). These were addressed by comparing the predicted energy extracted by simulation tools and the actual energy consumption produced by post occupancy evaluation.

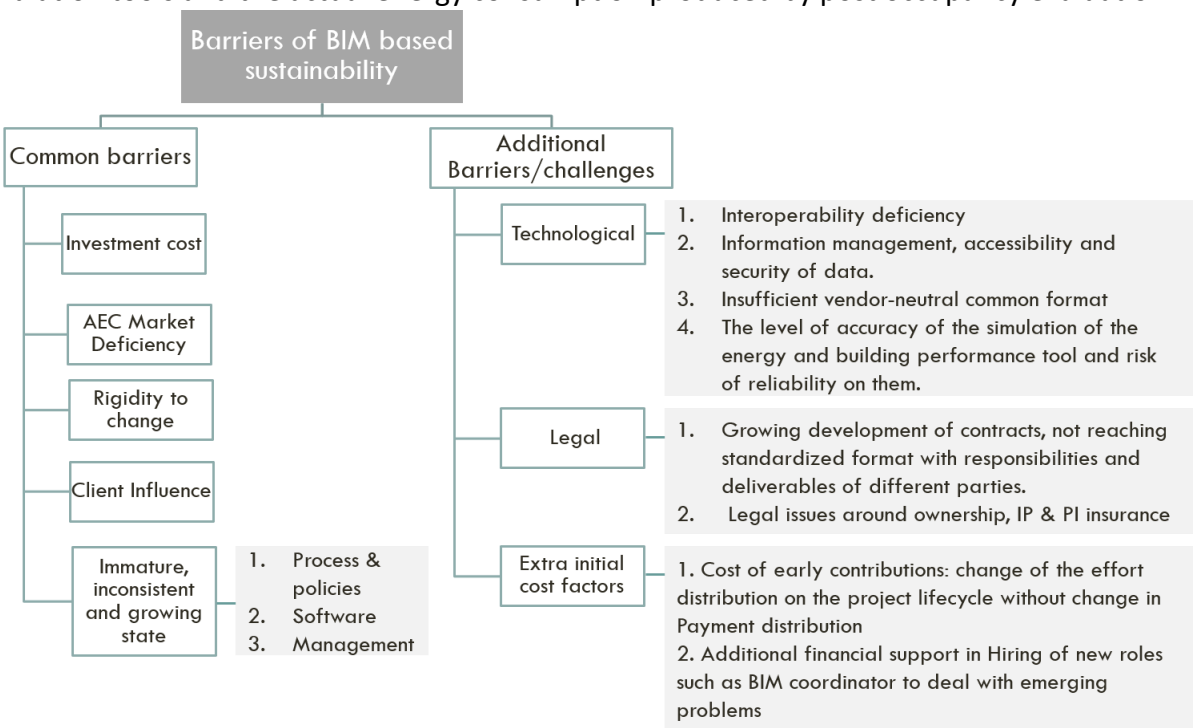

Figure 4. Common and Additional Barriers of BIM based Sustainability

Bridging the Gap between BIM and Sustainability

The correlation between the barriers for adopting green practices and benefits of BIM integration need to be highlighted. In order to bridge the gap between BIM and sustainability practices first the stakeholders need to be aware by the direct and indirect contribution of BIM in the short and long term. Then areas of development to reach consistent integrated design and execution method need to be identified. This section will discuss the expected impact of BIM, the problem in current practices and areas of development to achieve integrated method.

Direct and Indirect Impact of BIM based sustainability Adoption:

BIM has been identified as having characteristics for improving collaborations on project delivery. After reviewing the demand factors affecting the adoption of BIM based sustainability, it can be argued that the development in the BIM for delivering sustainable projects have direct and indirect impact to reduce the barriers of adoption. The first direct influence is guidance support environment that BIM framework offers to the project team for the responsibilities and the use of models and simulation results. Also, the approach of the

digital plan of work (*RIBA Plan of Work 2013*, 2013)(BSI, 2013) of the Information process through streaming, documenting graphical and no graphical data will allow project team to use and reuse previous project data. It can concluded from literature that the predicted direct impact of the potential use of BIM on the sustainability barriers can be listed as follows:

1. Decrease the risk of extension of project schedules due to repeat of work by ensuring design coordination, well communication and consistency.
2. Providing decision support framework for team guidance linked to the use new technologies and possibility of linking it to elements of the BIM model.
3. Compensating the high initial cost of the use non-convention green solutions by reducing the variation cost due to early collaboration.

The indirect influence will be on the market growth, covering the deficiency in both green suppliers and knowledgeable professionals. It is predicted that this will be achieved through the perceived higher value of service to client provided by professionals applying BIM. The high competition in market and need to increase the value of services to the clients will gradually impact the market deficiency in green suppliers, knowledgeable professionals and rigidity to change. The fair of the loss of competition and market share will gradually influence more practices to change their perspectives to provide the clients by their needs.

Problem in Current Practice

This paper allowed us to highlight the areas that need development in order to enhance the status of the synergy between BIM and sustainability. Figure 5, illustrated the main findings of this paper, which align the potential contribution of BIM to overcome some of the sustainability barriers. In order to perceive the synergy benefits, investigation is require for practice acceptance to new technologies to shape the development of mechanisms for change.

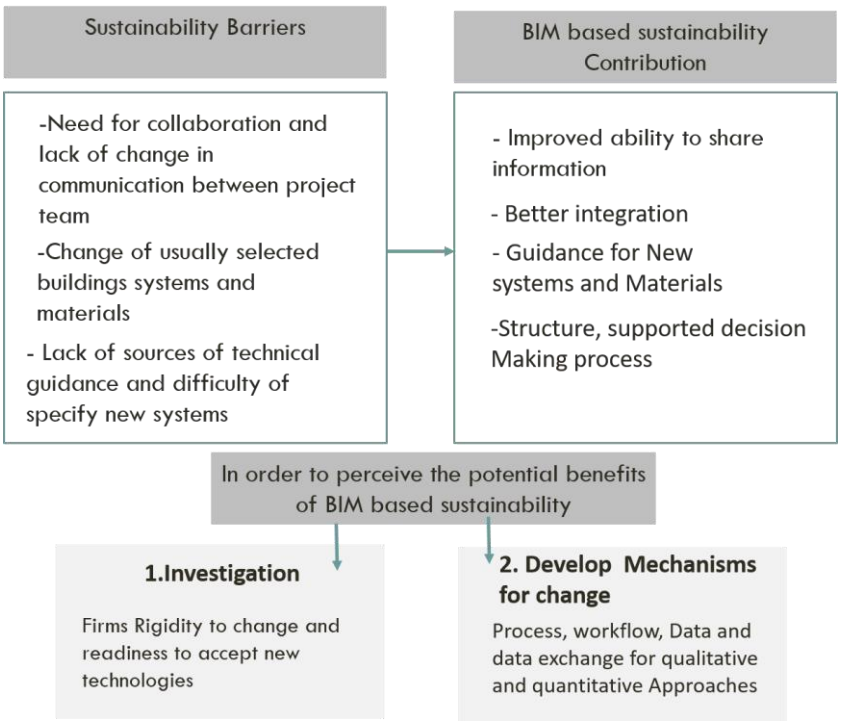

Figure 5 BIM based contribution and area of development

Improved collaboration targets are currently set for sustainability aspects), but are outside the BIM framework. Organizational aspects in terms of process, responsibilities, deliverables and communication for green building practices need to be investigated. Also, exploring the use of emerging tools for efficient integration are required to be able to contribute in reducing the barriers to deliver sustainable buildings. Accordingly, the alignment of sustainability and BIM strategies is crucial to maximize the perceived efficiency benefits of both the building performance and project workflow efficiency.

RIBA published green overlay in 2011 to the old version of the outline plan of work. (Gething, 2011)Although work for attaining credits in BREEAM are aligned in theory along the RIBA work stages, the practice is suffering from the divorce of the sustainability aspects within the BIM management process. Therefore, further work is needed to find mechanisms to motivate the change towards successful integration. This can be attained through improved ability to share information, in addition better access to the required information and guidance documents. Prior study was conducted by (Ayman, Alwan and Marzouk, 2017), which provided insight on disconnection between sustainability and BIM process. The findings presented deficiencies in the applications of theoretical framework suggested by RIBA and BRE that integrate the BREEAM credits on the stages in UK. Setting detailed sustainability targets, not applying early collaboration and considering sustainability aspects in late stages were the main findings highlighted in this study.

Further work and Mechanisms for Change

Further work is required in order to bridge the gap between BIM and sustainability to overcome this disconnection. First, a holistic picture need to be drawn on the current problems of green building delivery, using flied work investigation. Then, perceived benefits and the ease of use of possible synergy solutions need to be evaluated. Afterwards, a framework should be developed accordingly. This framework should allow project team to align the sustainability targets and criteria with critical decision points within BIM execution plan. Also, the work should investigate readiness of firms to accept change. The analysis of the current state of practices BIM-based sustainability, in addition to the future perceived benefits of adoption could act as indicators for future field acceptance to changes. The theory of Technology acceptance model (TAM) developed by Davis 1989 (Venkatesh and Davis, 2000) could be used to model the factors that influence the user acceptance to new technologies, TAM presented in fig. 6. Based on this theory a BIM-based sustainability acceptance model can be developed to be able to establish the mechanisms for change.

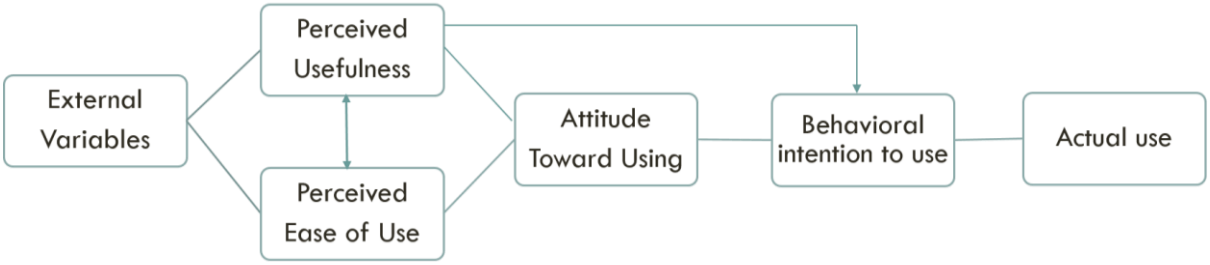

Figure 6 Technology Acceptance Model (Chuttur, 2009)

CONCLUSION

The purpose of this paper was to articulate the reasons behind AEC industry change in perspective and altitude. The drivers for adopting collaborative and green strategies in construction have been acting as a catalyst to change in the dynamics of AEC industry. This has resulted in the increased development and use of BIM based sustainability models. Focused on the driving forces and barriers of sustainability projects, and also adopting BIM, this study analysed and indexed the common categories that were discussed in previous literature. The relevance of the increasing recognition of the synergy benefits is clearly supported by the evolution of different themes in academia that are trying to deal with industry complexities. Yet, it is acknowledged that the synergy of BIM with sustainability aspects will not solve all the problems in construction industry efficiency, and other external obstacles highly affect the development. The findings of this paper provided insight into the areas that need development to reach a consistent and mature level of integration between sustainable aspects and BIM process. Essentially, it has been argued that more development is required in capturing the practice struggles with the alignment of sustainability work with the BIM process in terms of workflow, process, communication patterns, data, and data exchange. Other finding for the paper is gap that found in literature in providing solutions and framework for the synergy

developed from the problems reported by the industry with dealing and testing sustainability. Further work is required to analyse real-life project problems to reach sufficient framework. In addition, testing the impact of change in practice approach by investigating qualitative and quantitative perceived benefits and ease of use is crucial. This could be used as evidence to promote for BIM-based sustainability and predict technology acceptance rate in field work.

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TOWARDS AUTOMATED BUILDING ENERGY PERFORMANCE SIMULATION FOR BIM BASED RENOVATION PROJECTS

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Keywords: Renovation, Process Improvement, Scan-to-BIM, Energy Simulation

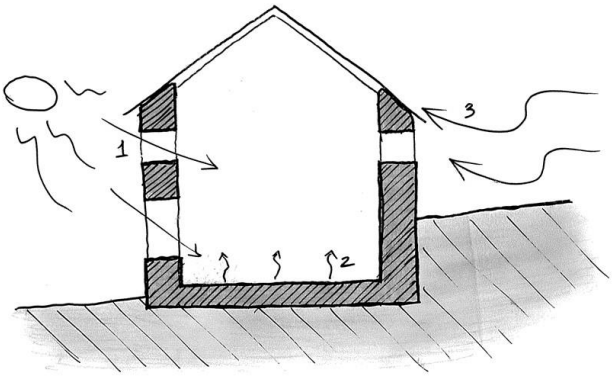
Abstract

Improving the acquisition, management and utilisation of existing building data is currently of great interest to industry and academia alike. Given the volume of older, and in the majority of cases, less energy efficient structures comprising the building stock, there is great potential to reduce carbon emissions for the sector as a whole. Based on an extensive review of current literature the research summarised herein was a reaction to the determined rationale that a reduction in the manual effort required to conduct Building Energy Performance (BEP) simulations may result in wider adoption of the method within the context of renovation. Capitalising on efficiency gains made possible through the use of available technologies, the research describes a semi-automated workflow aimed at minimising the manual effort involved in simulating BEP for existing buildings. The Building Information Modelling (BIM) based workflow uses open schema gbXML to provide seamless interoperability between a Single Analysis Model (SAM), containing building and energy data, and multiple BEP simulation tools. This SAM method provides an improved workflow to the status quo. The findings of the research are of relevance not limited to the context of renovation, but have implications to the wider Architectural, Engineering and Construction (AEC) industry, which is currently undergoing a digital transformation. Further research and development aimed at improving exchange schemas is recommended to allow for the collaborative functionality demonstrated in this project, as well as adapting aspects of the format to be more attuned to a renovation context given the acute need for thermal improvement across the building stock. This research contributes to the body of knowledge by proposing a novel approach to integrating BIM with BEP simulation. It provides a development model for others wishing to undertake process improvement in similar fields, and can also be read as a practical guide to multidisciplinary collaboration through the BIM platform.

INTRODUCTION

On the global scene, the United Nations Climate Conference (COP21) report (*The Paris Agreement*), article 10:5, emphasised that organisations and corporations will have to change and improve the way they do their business in order to achieve a long-term, global response to climate change, promoting economic development, and sustainable development (United Nations Framework Convention on Climate Change, 2015). With the increasingly apparent negative effects of climate change, and considering that buildings account for around a third of greenhouse gas emissions (UNEP 2009), the construction industry's carbon footprint has become a major target for reform. Environmental strategies

in the sector have mainly focussed on the early design stage of new building projects where, individually, the greatest impact can be made (Jalaei & Jrade 2014). However, given that the building stock consists largely of older, and in the majority of cases less thermally efficient structures, renovation practices which reduce energy requirements become imperative.



1. Solar gain is maximised by orienting fenestration to the South
2. Heat is absorbed in the thermal mass during the day and released slowly
3. Heat loss is minimised by reducing the surface of façade exposed to the prevailing wind direction

Figure 1. Environmental design strategies employed in vernacular construction

Energy efficient design strategies are evident throughout the history of construction (see Figure 1). To date, these environmental design strategies have been largely based on generalisations and generic data not specific to the unique situation (Thomas 2006). More recently however, digital thermal modelling tools have begun to enable complex energy simulations which dynamically calculate the many heat transfer methods in a building (see Figure 2. below). These tools assist building designers in strategic environmental planning, however, the technology remains underdeveloped in terms of its integration within the current design framework in the AEC industry, namely BIM, as well as its limited application for renovation projects. It is widely agreed in the literature that a major drawback to simulating for BEP in renovation projects is the great manual effort involved in collecting, exchanging and utilising existing building data (Wang & Cho 2015; Korhonen & Laine 2008).

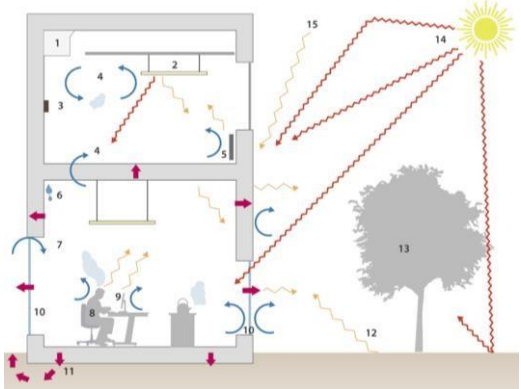


Figure 2. Heat transfer mechanisms in a building, adapted from EDSL (2016)

The aim and objectives of the research

To address the aforementioned issue, and by the rationale that in doing so the practice may become more widely employed, ***the aim of the research was to develop a workflow which would reduce the manual effort typically required to perform BEP simulations in renovation projects by improving data exchange at various stages of the process***. A Single

Analysis Model (SAM) method was developed by exploring and testing automated and semi-automated processes in an effort to improve on the status quo. To validate the practical application of the developed workflow, three collaborative functions were proposed (Table 1).

Table 1. Single Analysis Model development aims

Development	Approach	Validation
Complex Geometry	select a small, suitably complex building with which to test complex geometric arrangements	successful data transfer between the SAM and multiple simulation software platforms
Change Management	implementing the monitor function in Revit between the architectural BIM and SAM	demonstrate architectural design modification communicated through the CDE*, resulting in automatic updates to SAM while maintaining clean export geometry
Design Options	implementing the design options function in Revit, coordinating this design intent between the architectural BIM and SAM	resulting in multiple simulations, the data of which can be compared within the SAM environment in a visually meaningful way

*Common Data Environment

Research Questions

Based on an extensive review of current literature, a number of research questions were posed to be addressed in concluding the research. Some of the questions which the research ultimately sought answers for were:

- How effective are available technologies in reducing manual effort in a renovation BEP simulation workflow?
- Which aspects of the process can be automated, which require human input and what are the limitations to further automation?
- What should be the considerations when designing experimental automated processes?
- What should be the considerations when establishing a project of this type?

The questions were considered throughout and are addressed in the *Conclusions* chapter of the research report (Shaw, 2017). A number of these points will be discussed in concluding this paper.

DEFINITION OF BUILDING AND SYSTEMS

Site selection

A suitable site was required with which to test the proposed workflow. The selected site is located in the foothills of the Cooley Mountains, on the border between Northern Ireland and the Republic of Ireland. The site consisted of a series of dilapidated 18th Century farm buildings including a cottage, cow shed and chicken coop.

Address: Proleek, Co. Louth, Ireland
GPS Coordinates: 54°02'24.1"N 6°20'56.1"W

Figure 3. Site location (Google Earth)

The cottage building was chosen as the subject for testing the proposed workflow, a two storey vernacular *Direct Entry* pre-famine farm house dating from before 1800 (exact date unknown). The main structure is of limestone block walls with rubble infill and sits on a stone foundation with a more recent concrete ground floor. The timber intermediary floor and roof structure, finished with slate, were added following the removal of a thatched roof in 1937. The building features three fireplaces and (the following dating from the 1937 alteration) timber sash window frames, stairs and interior panelling.

Renovation design

Three renovation design options were developed to demonstrate the SAM functionality:

1) Minimal intervention (no insulation, repair only)
2) Medium intervention (insulation in roof and floor + earthworks)
3) Considerable intervention (insulation in roof, floor and walls + earthworks)

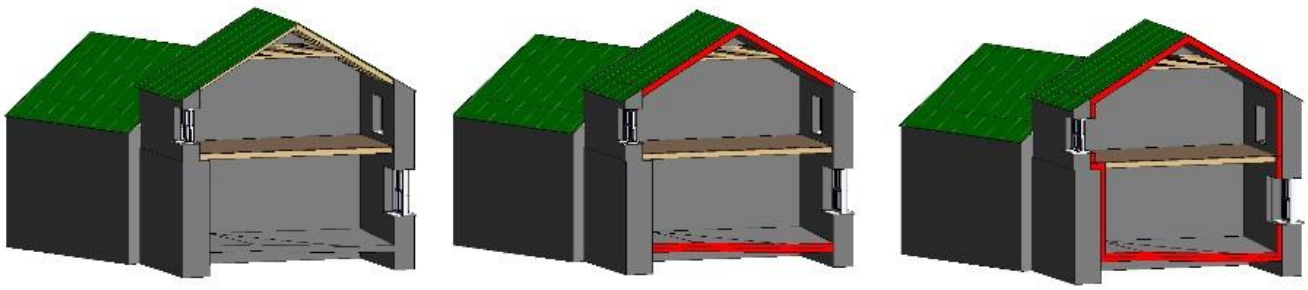


Figure 4. Renovation design options (additional insulation indicated in red)

RESEARCH APPROACH

This is a descriptive case study which outlines a novel solution to the stated problem; the typical requirement of great manual effort to undertake BEP simulation in renovation projects.

Workflow concept outline

Figure 5. represents graphically the developed workflow concept which was carried out on the test site. The following sections describe the practical steps which were taken during the research project.

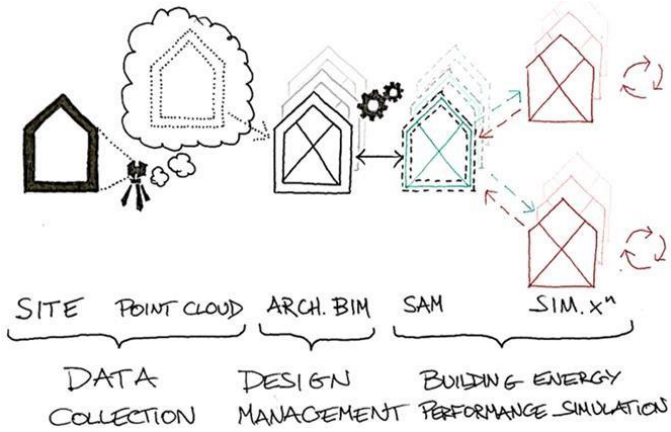


Figure 5. Developed workflow concept 3.2 Definition of scope

The project investigates the transfer of various types of building data across multiple software platforms. Data collection focussed on geometry due to the inability of the scanning technology employed to gather information about materials' thermal characteristics or the environment.
Assumptions were made throughout to account for this data required for the simulations. Validating absolute values against in-situ measurements was outside of the project scope.

Data collection

Terrestrial Laser Scanning (TLS) is gaining acceptance as the industry standard for geometric data capture about structures and places, particularly in a conservation context due to the inherent lack of uniformity in traditional systems. The ability to capture millions of spatial points and guarantee millimetre accuracy, reduces the manual effort which has been associated with conducting surveys, and results in a highly detailed and information rich dataset known as a *Point Cloud*.

Figure 6. Terrestrial Laser Scan survey of the test site resulting in a point cloud dataset

In April 2016 a 3D Terrestrial Laser Scan was carried out at the test site using a *Leica C10* scanner. The resulting scan data was registered into a point cloud dataset using *Leica Cyclone* software and contained a total of 103,628,626 individual (x,y,z r,g,b) measurements.

Generating BIM geometry

Autodesk Revit 2016 was chosen as the BIM authoring tool. An existing condition BIM was created by manually tracing over and generating geometry from the point cloud. It is widely acknowledged that developing a BIM in this way requires great manual effort and skill and is a contributing factor hindering the wider adoption of BEP simulation in renovation projects (Tommasi et al. 2016). In order to reduce this effort, a semi-automated *Scan-to-BIM* method was then used and the techniques compared.

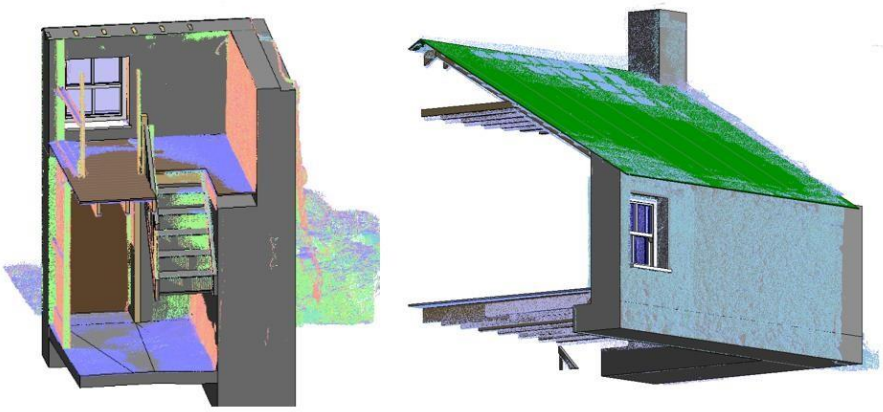


Figure 7. Manual modelling from the point cloud

For the semi-automatic BIM generation step, the leading Point Cloud extraction tool was used (Son et al. 2015). *Edgewise 3D* is a software application which uses advanced *Scan-to-BIM* algorithms to generate BIM objects. The term *semi*-automated is important to note as, due to limitations of the software, this method requires some manual work to bring the BIM up to the required detail for thermal analysis.

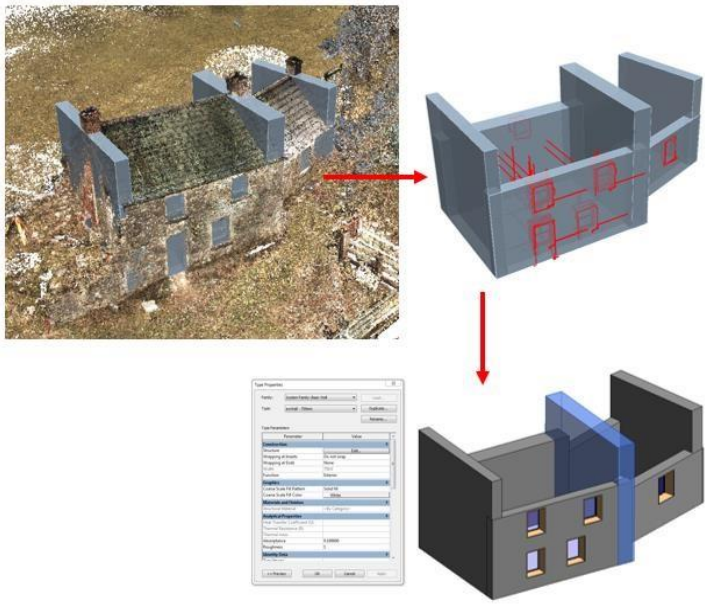


Figure 7. Walls and windows detected in Edgewise 3D and exported to Revit as native families

Generating the Single Analysis Model (SAM)

The Single Analysis Model (SAM) or *energy view* of the building, comprises a simplified version of the architectural BIM, intelligently linked using *monitor* functions in Revit through a Common Data Environment (CDE). The method was developed in partnership while one of the authors was employed with *BuroHappold Engineering* in Berlin during 2016. The simplified geometry enables seamless export through open exchange format gbXML to multiple simulation packages. It is widely understood that *usually* more than one simulation software program is required in design projects, as each performs specialty operations (Welle et al. 2011). In the SAM approach the multiple resulting simulated datasets are linked back into the SAM and values are displayed within the model space, where the data can be most useful to designers. The steps for creating the Single Analysis Model for the test project are described in more depth in the project research report (Shaw 2017).

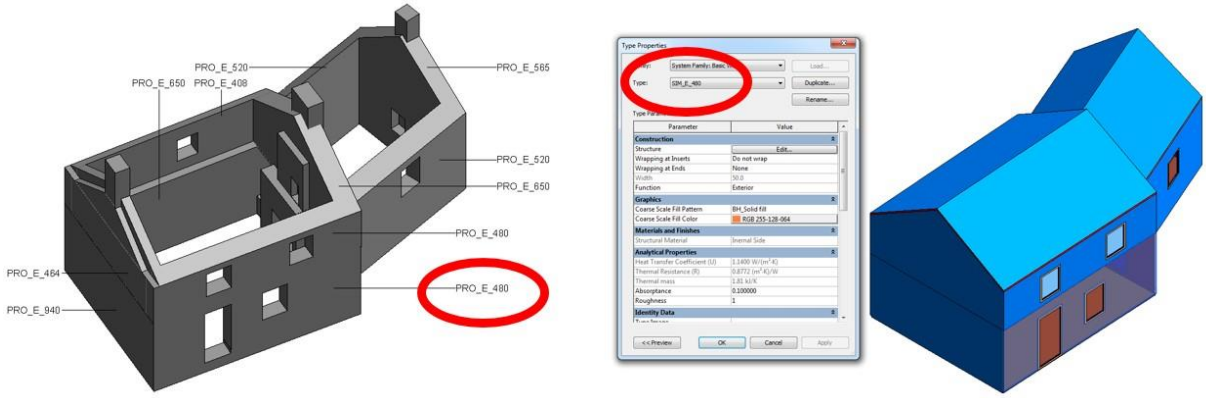


Figure 8. Architectural BIM construction types, and the associated, simplified SAM version

TESTING AND RESULTS

Validating clean (complex) geometry

Using the open format gbXML schema, the Single Analysis Model was exported to two Building Energy Performance simulation software platforms. *EDSL TAS* (version 9.9.3.b) was used to perform a thermodynamic simulation, resulting in annual heating and cooling loads. *Solar Computer* (version 5.15.01) was used to calculate the worst case scenario through a steady state heat loss calculation method, providing a power requirement. The use of this second software validated the multi-domain application of the SAM method.

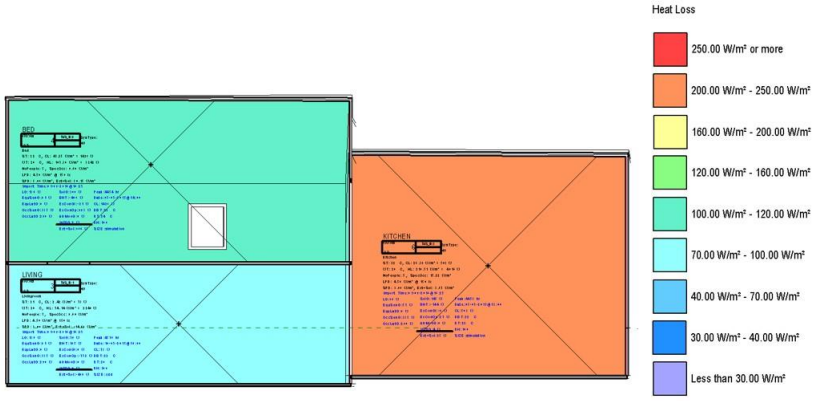


Figure 9. Results from multi-domain BEP simulation displayed in section in the SAM

Simulations were conducted in the respective software and the resulting data was imported back into the SAM, displaying information via population of custom *Space Tags*. Data is managed using the BIM space objects' Globally Unique Identifier (GUID) and an open source third-party plugin (*TASmanianDevil*) which was used to move data. Applying native Revit functionality, the results were visualised in an understandable way by intelligent colour coding of spaces in the views.

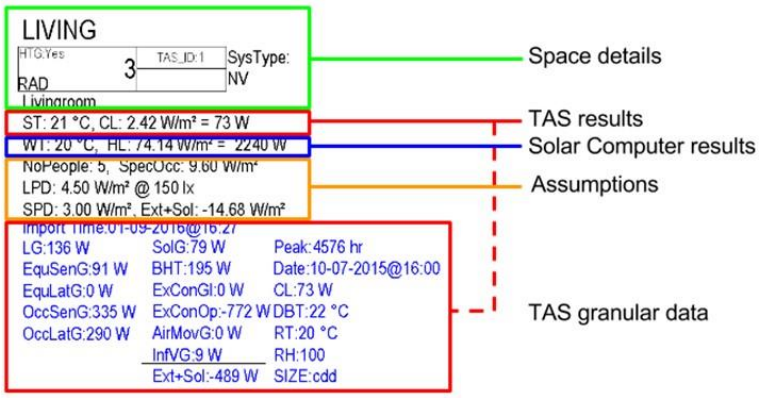


Figure 10. Results from TAS and Solar Computer populating a custom Revit *Space Tag*

Demonstrating change management

It has been the experience of the authors that a major contributor to tedious manual effort, even in a relatively integrated BIM to BEP workflow, occurs when changes in the

architectural design require the simulation model(s) to be manually updated. By using the *copy/monitor* function between the architectural BIM and SAM this was greatly reduced, as demonstrated below.

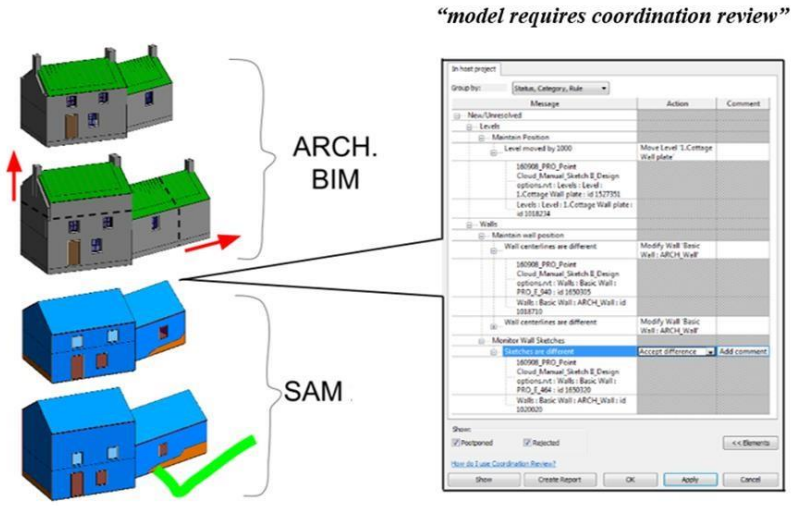


Figure 11. Approach to change management employed in the workflow

Following a change in the architectural BIM, Revit provides a notification dialogue describing the changes, whereby the energy modeller may decide on an appropriate action. Once accepted, the SAM is automatically updated.

Providing design alternatives

Design options were built into the SAM process. The three architectural design options were successfully simulated, however in doing so it was felt by the authors that the process became overly complex. Although it was outside of the scope of this research to validate absolute simulated results against in-situ measurements, the provision of design alternatives allowed for comparative analysis of refurbishment measures. As expected, there was a positive correlation between increasing insulation and incremental energy savings between the design options.

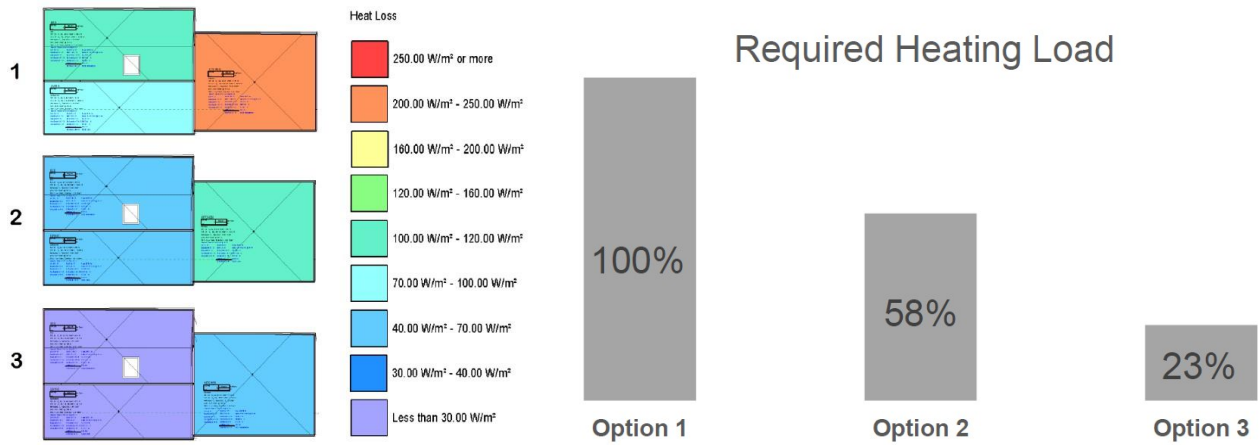


Figure 12. Positive correlation between adding insulation and a reduction in energy requirement

DISCUSSION, CONCLUSIONS AND REFLECTION

Discussion

In the previous section, the developed SAM functionality was demonstrated and the results summarised. To some degree, the overall developed SAM method achieved the targets outlined in the research objectives (*Table 1*) by providing improved functionality, enabling a reduction in effort downstream, and improving collaboration and coordination between the theoretical multidisciplinary team. Even so, the complex processes described in this research support the early conclusion that in order for potential savings to be realised, significant cooperation between disciplines is necessary, including an aptitude for, or at the very least familiarity with, the technical details of one another's design processes.

To discuss the results of testing, firstly, the successful multi-domain export/import for simulation of the **Complex Geometry** of the cottage validated the ability of the method to handle complexity. The workflow demonstrated a significant reduction in manual effort required to simulate building energy performance, bypassing the need to create various native energy models and preparing the simulation team for downstream re-work in an efficient way. The ability to both display the results in the SAM environment and to use that information to create meaningful representations using gradient fills (see *Figure 9*) represents a mechanism to maximise the use of simulated energy data in an indicative, coherent way. It should be understood, however, that this method was not possible using *out-of-the-box* Revit functionality and relied on a custom tool, namely an open source third party plugin, *TASmanianDevil*, which was used to move raw simulation data. It is the prediction of the author that this may be what the future building design software landscape resembles: mediocre, highly specific disciplinary software applications, a lack of cooperation between vendors/strategic misalignment, resulting in a multitude of custom plugins being developed by the users to make it all work. The sharing of these custom tools would be at the discretion of the individual developers, and a positive outcome in this case relies on the cultivation of healthy open source principles within the community.
Secondly, the successful demonstration of **Change Management** functionality represents a considerable downstream saving in tedious manual effort by automatically implementing architectural changes into the SAM. It is this feature in the method which was most readily deployable and was immediately implemented in a live project at the partner company, where the dynamic simulation of over 1700 spaces required strict alignment to an ever changing architectural design. It is clear that automating the adaptation of a SAM to design changes is of great benefit to efficiency. However, perhaps the more significant point to acknowledge is the important *approval mechanism* which was established. The facility for the energy modeller to review design changes and make decisions accordingly, is an important definition of responsibility. The implication is that, in establishing automation in a process, an understanding of contractual relationships, responsibility and authority is essential and should be logically built in.

Finally, the ability of the SAM to enable the exploration of multiple **Design Options** resulted in three gbXML arrangements being exported from a single model. The resulting data showed a

positive correlation between additional insulation and a reduction in energy consumption, as was expected. In this context, the true potential of graphically depicting the simulation results can be appreciated, the non-technical individual comprehending with ease the outcome of this complex calculation (see *Figure 12*). As discussed in section 3.2, *Definition of Scope*, by providing design alternatives in a BEP simulation process, regardless of the ability to validate *absolute* values, useful comparative analysis can be drawn from the results (Maile et al. 2007). Both simulation tools were prolific in their production of data but what can be understood of the two methods is; a) an approximate idea of the thermal comfort and energy use pattern of the building and b) a percentage reduction in the size of mechanical equipment required to run the building. This information is of great importance in a renovation context and the authors believe that wider access to such information would have a positive impact on environmental design.

Overall, the research demonstrates that a reduction in the effort required to simulate BEP in renovation projects is possible through the use of state-of-the-art IT and software. Automating some of the manually intensive tasks was shown to be feasible without losing sight of disciplinary responsibility through quality assurance steps built into the processes. Such significant efficiency gains may likely result in wider adoption of BEP simulation methods (as inefficiency, according to literature, is currently the main barrier to greater use) and improve the scope for environmentally motivated design decisions in renovation projects.

Conclusions

The research demonstrated that considerable automation was possible through the use of commercially available technologies, but that the main barrier to realising their potential in concert with each other, was a lack of interoperability between software platforms through open exchange formats, namely gbXML. In addressing the research questions, the study revealed that building validation steps into automated processes is critical to ensure sufficient oversight, that investing in model intelligence between disciplines early in a project can significantly reduce the burden of later design changes, and that some manual tasks are important familiarisation steps for a designer and automating them should be carefully considered.

These answers to the research questions are of relevance, not just in the specific context of renovation design but also have implications to the wider AEC industry, which is currently undergoing a digital transformation. Further research and development is recommended to improve exchange formats to enable the collaborative functionality demonstrated in the project as well as adapting the schema to be more suited to a renovation context, given the acute need for environmentally inclined renovation strategies. This research contributes to the body of knowledge by proposing one novel example of how BIM and BEP simulation may be integrated in a renovation context. It provides a development model for others wishing to undertake process improvement, and can be read as a practical guide for collaboration through the BIM platform in a multidisciplinary setting.

Reflection

Since the publication of the research in 2017, the Single Analysis Model method has been implemented to varying degrees in a number of large projects at *BuroHappold Engineering,* Berlin. The findings of the research have had impact where they have provided guidance for the team as to which aspects of the SAM methodology to use for certain projects, such as the deployment of the change management feature as discussed previously, and has been widely hailed as a success throughout the company.

The surveying partner in the research project, Farrimond MacManus Ltd, had their first contact with BIM as a survey output in this project. They have since gone on to complete four medium to large surveys for conservation projects with BIM *a*s the output. The mandate for *BIM Level 2* for public projects in the UK is having a noticeable effect on client demand in Northern Ireland. Having said this, it is unclear at this stage how holistically the adoption of BIM really is in these types of projects. The general feeling is that the requirement for BIMs by clients is a *tick-the-box* outcome of the government mandate and their effective utilisation at this stage remains questionable.

The *Scan-to-BIM* methodology is proving year-on-year to be a significant development, bridging a major gap in the industry; however it remains quite limited for use in a conservation context. With a lack of market demand in this sector, the technology continues to be ever more focussed on large industrial facilities and infrastructure, encouraged by economies of scale and the resulting profits. It would appear that adopting this sort of technology as the industry standard, based on proven efficiency gains to the taxpayer, falls into the jurisdiction of legislation in a similar way to the controversial mandate for BIM. From discussion with the software vendors it is understood by the authors that the shape recognition technology used in *Scan-to-BIM* applications certainly has the potential to be applied in a conservation context. However, as it relies on matching scan data to library components, the more Historic Building Information Model (HBIM) families that come on the market, the greater the potential it has to be implemented. This inspires a call for greater focus on the development of an open source HBIM library.

Debate on where to strike the highly subjective balance between the accurate representation of an existing built asset while providing a most usable BIM, continues in the industry discourse, however an emerging theory has come to the authors' attention which seeks to address this dilemma. Similarly to the faculty of a BIM to represent multiple meanings to various actors through Model View Definition (see section 2.3.1 in the research report, Shaw 2017), so too does the concept of *Multi-representational* BIM objects aim to potentially provide an *as-close-to-reality* depiction of an existing building while allowing for a *most-functional* BIM element. Those working in the area of conservation should maintain an awareness of the development of this concept, as speculation on the formation of the theory is currently a hot topic for software vendors and other technological forecasters in the industry.

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A COMPARATIVE ANALYSIS BETWEEN THE PROVISION OF MONETARY AND NONMONETARY INCENTIVES TO ACHIEVE HEALTH AND SAFETY PREVENTION MEASURES IN CONSTRUCTION PROJECTS

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Keywords: Construction projects, Health and Safety (H&S), monetary incentives, Non-monetary incentives

Abstract

This study is aimed at making a comparative analysis between the provision of monetary and non-monetary incentives to achieve health and safety prevention measures in construction projects. Design - The study adopted a deductive approach whereby hypothesis was formulated based on motivation theories, specifically monetary and non-monetary rewards and applied them in construction project situations. A web survey was adopted for the empirical data gathering by means of a questionnaire emailed to nationwide selected construction and consultant firms. A seven point Likert scale questionnaire was developed and paired-sample t-test was used to analyse the data using SPSS. The reliability test was done using Cronbach's alpha coefficient of reliability. Findings - In total of 164 respondents who participated in the study, 147 valid cases were analysed. The test of reliability showed results were highly reliable. A paired-sample t-test revealed there was a statistically significant increase in scores from monetary to non-monetary incentive factors including selecting contracting candidate on the basis that they have H&S plan, the integration of H&S plan in design, and the contractor having a programme for counselling and testing of diseases. Although other factors displayed no statistical significance, they also consistently displayed higher mean scores of non-monetary incentives than monetary incentives. Thus the construction industry favours more the provision of non-monetary incentives than monetary incentives to achieve H&S preventive measures. Value – Findings reveal the current standoff of the South African construction industry attaching higher importance on the provision of non-monetary incentives than monetary incentives in achieving H&S prevention measures. Therefore, these findings imply more has to be done to change the mind set of construction participants to move towards a proactive procurement environment enabling the incorporation of both monetary and nonmonetary incentives to achieve H&S prevention measures.

INTRODUCTION

The South Africa government has been committed to the promotion of the health and safety of employees at the workplace. Given such a commitment, a related legislation has been formulated, namely, the Occupational Health and Safety Act No 85 of 1993 which has been passed. The Act was to provide for the health and safety of persons at work and for the health and safety of persons in connection with the use of plant and machinery and the protection of persons other than persons at work against hazards to health and safety arising from or in

connection with the activities of persons at work (Government Gazette, 1993:1). Smallwood and Haupt (2005:2) indicate that large-scale construction accidents in South Africa in recent years and consequent media coverage have raised the level of awareness of the importance of health and safety. In order to achieve health and safety requirements on site, both proactive and reactive measures are employed. Proactive measures consist of prevention measures while reactive measures consist of a decision taken as a remedial action to address anticipated H&S failure. This study will only be confined to H&S prevention measures as a project objective aligned with the provision of monetary and non-monetary incentives.

In the context of the study, monetary incentives should be understood as any kind of reward given to construction project participants for achieving a certain goal. Various forms for providing monetary incentives include:

- Transferring monetary reward to individuals who achieved certain goals;
- Monetary incentives awarded individually to only team members who achieved specific goals;
- Monetary incentives shared among team members; and
- Monetary incentives transferred to the employing company.

Non-monetary incentives should be understood as rewards that do not involve any monetary payment, such as verbal or written recognition of good work and participation in decision-making (Yavuz, 2004:iv). The incentives which cannot be measured in terms of money are put together in the category of "non-monetary incentives". Some examples of nonmonetary incentives are: encouraging employees by providing them with autonomy in their job and participation in decision-making, assigning challenging duties, improving working conditions, recognising good work through small gifts, letters of appreciation.

While monetary and non-monetary incentives have been recognised as motivational tools compelling individual employees to achieve certain goals; arguably, the South African construction industry has not fully exploited the various avenues to initiate motivational approaches aligned with project objectives to enhance successful delivery of construction projects. The objective of this study is assess the perception on the importance of monetary and non-monetary incentives in motivating project participants to achieve health and safety prevention measures. Typically, the study will make a comparative analysis between mean scores of similar statements of H&S prevention measures matching them with both monetary and non-monetary incentives compelling construction participants to achieve health and safety objective. Hence, the hypothesis will test whether there is any statistical significant difference between mean scores of monetary and non-monetary incentives. Respondents will base their response to a project they have been personally involved in.

H&S PREVENTION PLAN IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

The continuing poor health and safety performance of the construction industry in the form of fatalities, injuries, and disease, the large scale construction accidents and the general nonparticipation by key project stakeholders such as the clients and designers, provided a catalyst for a new approach, which culminated in the promulgation of consolidated construction health and safety legislation in the form of the Construction Regulations on the 18

July 2003 (Smallwood & Haupt, 2005:2). Smallwood and Haupt (2005:2) indicate that the construction regulations required a range of multi-stakeholder interventions, inter alia, that designers substitute hazardous materials, amend designs that necessitate the use of hazardous processes, and consider ergonomics during the commissioning and other phases of the project. Unfortunately, the construction industry still has a poor global health and safety record and South Africa is no exception (CIDB, 2009:1). Deacon, Smallwood and Haupt (2005:172) reiterate that the construction industry has the reputation for being a particularly unhealthy industry because of its highest rate of work-related illnesses across all occupational groups. CIDB (2009:1) indicates that the construction industry continues to contribute a disproportionate number of fatalities and injuries and there continues to be a high level of non-compliance with the health and safety regulations.

CIDB (2009:17) indicates that high health and safety standards are achieved on projects when clients are committed to health and safety and provide appropriate management oversight. Construction health and safety performance is influenced by the health and safety specifications and communication of health and safety expectations and requirements from one participant to the others, and importantly, on the effective monitoring of and compliance with these expectations (CIDB, 2009:17). Participants include clients, project managers, designers, quantity surveyors, contractors, and subcontractors and these can influence compliance with health and safety in one way or another. Haupt and
Smallwood (2000:47) indicate that designers, architects, and particularly clients influence the construction process and if that influence were used with accident prevention in mind, from project inception through project execution and then throughout the life of the facility until its demise with the demolition phase, a great contribution to the avoidance of accidents would have been made.

Given the unique position of project managers as they effectively integrate design and construction, they can influence health and safety specifically (CIDB, 2009:19):

- During the upstream phases of design, namely concept design, preparation of working drawings and design coordination meetings;
- Through design reviews, including elevations, details, finishes and schedules, and various characteristics of materials;
- Through integration of design and construction, realise an optimum client brief, finalise design before construction commences, discourage client changes; and
- Through prequalification or selection of contractors on health and safety and quality, including a specific mention of and financial allowance for health and safety in contract documentation, avoiding competitive tendering and realising the implementation of quality management systems in the design and construction.

Given that HIV/AIDS has become a pandemic in the construction industry, the CIDB (2008:22) recommends that construction workers be exposed to an interactive workshop for a minimum duration of two and half hours covering the specific learning outcomes of following units: the nature of HIV/AIDS, transmission of HIV infection, HIV/AIDS preventive measures, voluntary HIV/AIDS counselling and testing, living with HIV/AIDS, treatment options for people with HIV/AIDS, and the rights and responsibilities of workers in the workplace with regard to HIV/AIDS.

The inclusion of an incentive allowance whether in form of monetary or non-monetary reward in a construction project would be an indication of the commitment to the improvement of health and safety. CIDB (2003) has issued generic specification for public commitment towards the awareness and prevention of HIV/AIDS on site. Among other objectives, the awareness programme is aimed at reducing the risk of transfer of HIV virus between and among construction workers and the local community, and assist affected individuals to access care and counselling (CIDB, 2003:1). Given that the contractor is entitled to claim for reimbursement of health and safety incurred cost, this means H&S has to be included into the budget for the project. However, it should be noted that there are other factors other than incentives that can be used to ensure H&S achievement on construction sites. Wells and Hawkins (n.d.: Online) emphasise the procurement process can promote health and safety in developing countries. Wells and Hawkins (n.d.: Online) propose H&S issues should be considered from pre-tender to post-project evaluation stages. However, the Government of Hong Kong (2002:8), during the construction of deep water tunnels, contractors were entitled to a monetary incentive bonus payment for a high score in a safety audit of the site, and a low score would meant underperformance attached with severe penalty. An underperforming contractor would miss future tendering opportunities. This is a clear indication incentives are among useful tools used to achieve H&S prevention measures.

METHODOLOGY

A quantitative method was used through a survey questionnaire designed with closed-ended questions. One section was dedicated to biographic profile of respondents and the other section consisted of questions testing the alignment of project objectives with monetary and non-monetary incentives; specifically focusing on Health and Safety (H&S) prevention measures. Likert scale questions were in the following format: 1 = unimportant, 2 = little important, 3 = somewhat important, 4 = important, 5 = very important, 6 = extremely important, 7 = utmost important, and U = Unsure. A web survey strategy was used to gather the empirical data whereby a questionnaire was distributed nationwide by email. Given the exploratory nature of the study, the study was confined to seeking the opinion of professional stakeholders engaged into construction projects, and they were asked to base their responses to the project they have personally been involved in. These include contractors, cost consultant, project managers, and consulting engineers.

Likert-type or frequency scales use fixed choice response formats and are designed to measure attitudes or opinion levels of agreement/disagreement (Bowling, 1997: 34). Using a 7 point Likert response format allows the respondents more granularity and hence better decision-making to express how much they agree or disagree with a particular statement. When using Likert-type scales it is imperative to calculate and report Cronbach's alpha coefficient for internal consistency reliability for any scales or subscales one may be using (Gliem & Gliem, 2003: 88). Reliability is the extent to which a measuring instrument is repeatable and consistent (Maree & Pietersen, 2007: 214). For this particular study, the internal reliability of variables was tested using Cronbach's alpha coefficient of reliability. Maree and Pietersen (2007: 216) suggest the guidelines for the interpretation of Cronbach's alpha coefficient as follows: 0.90 – high reliability, 0.80 – moderate reliability, and 0.70 – low reliability.

Both descriptive and inferential statistics were used to analyse the data. Descriptive statistics consisted of mean scores and standard deviations. Mean scores are an appropriate yardstick to measure the difference between two variables. In the context of this particular study, both mean scores of statements related to monetary and non-monetary incentives were compared. While mean scores are not enough to conclude whether the difference between two means is significance, inferential statistics reveal whether the statistical difference is significant or not. The difference was significant where for significance with the value of 0.05 or less. Inferential statistics consisted of paired-samples t-test. The Paired-samples t-tests can be used to measure the same person in terms of response to two questions as long both dimensions are rated the same scale (Pallant, 2013:252). The T-test is a parametric test used to examine hypotheses related to the population means (Fellows & Liu, 2008:194).

FINDINGS

Research participation

In total 164 respondents participated in the study, among them 80.5% (132) were males and 19.5% (32) were females, and this suggests both genders were represented in the study. Table 4.1 shows that participant companies included mostly contractors (26.6%), project managers (19.8%), architects (16.7%), quantity surveyors (16.7%), and consulting engineers (8.0%). There were 2 missing values.

Table 4.1 Participant companies

Company	No.	%	
Contractor Grade 2	1	0.6	26.6
Contractor Grade 3	7	4.3	
Contractor Grade 4	5	3.2	
Contractor Grade 5	7	4.3	
Contractor Grade 6	8	4.9	
Contractor Grade 7	9	5.6	
Contractor Grade 8	1	0.6	
Contractor Grade 9	6	3.7	
Project Manager	32	19.8	
Architect	27	16.7	
Quantity Surveyor	27	16.7	
Consulting Engineer	13	8.0	
Government	4	2.5	
Academic	3	1.9	
Agent	2	1.2	
Construction Consultant/Developer	2	1.2	
Engineering	2	1.2	
Logistics	2	1.2	
Property Consultant	2	1.2	
Parastatal	1	0.6	
Construction Regulatory	1	0.6	
Total	162	100.0	

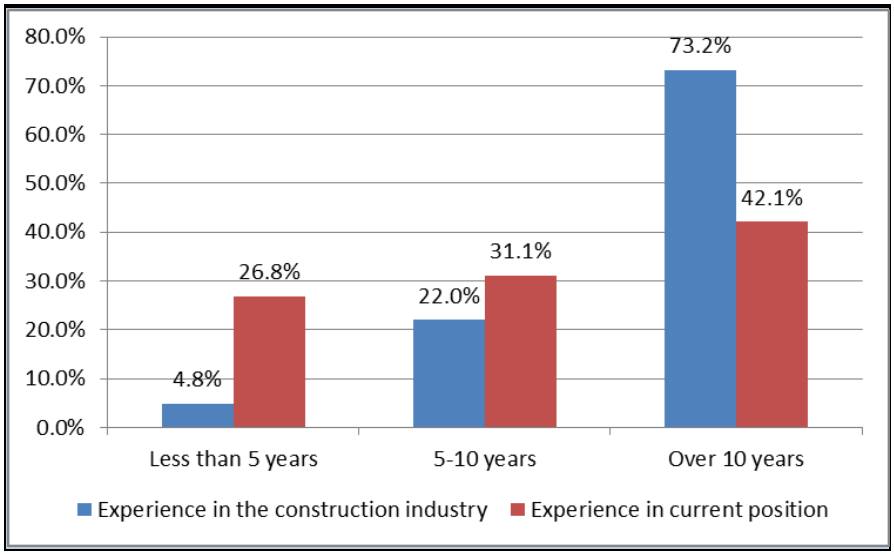

Figure 4.1 Experience of respondents

Figure 4.1 shows that 73.2% of the respondents had experience in the construction industry of more than 10 years, 22.0% between 5 and 10 years, and 4.9% had less than 5 years. Almost half of respondents (42.1%) had been in their current position more than 10 years, 31.1% of them had between 5 and 10 years, and 26.8% had less than 5 years.

Table 4.2 shows that participants have recently been mostly involved in commercial (16.7%), residential (16.0%), educational (11.1%), administrative (10.5%), infrastructure (9.9%), and health facilities (9.3%) construction projects. Survey results showed that respondents were employed in various companies other than the prescribed ones. The fact that the respondents have probably moved from one type of company to another (e.g. Consultant to Academic) would not preclude their professionalism or abilities such that their response would be invalid. This suggests respondents had a wealth of experience accumulated from various construction fields. It was deemed worthwhile not to reject any response as long as the respondent worked for a construction related company.

Table 4.2 Type of project participants have been involved in

Project	No.	%
Commercial	27	16.7
Residential	26	16.0
Educational	18	11.1
Administrative	17	10.5
Infrastructure/civil	16	9.9
Hospital/health	15	9.3
Industrial	9	5.6
Mining	7	4.3
Correctional services/chancery	6	3.7
Entertainment	6	3.7
Hotel/motel	3	1.9
Power station	3	1.9
Bulk water/pump station	2	1.2
Renovations and alterations	2	1.2
Airport	1	0.6

Colliery	1	0.6
Marine	1	0.6
Mechanical engineering	1	0.6
Petrochemicals	1	0.6
Total	162	100.0

Test of the reliability

Table 4.3 reports the reliability of factors of prevention measures towards achieving H&S standards through monetary and non-monetary incentives. It is shown that the study produced highly reliable measures of 0.97 and 0.98 for monetary and non-monetary incentives respectively.

Table 4.3 Reliability analysis

Factors	N	Mean	Reliability		
			No. of items per question	Cronbach's alpha	Comments
Monetary incentives	147	4.71	7	0.98	High reliable
Non-monetary incentives	148	4.94	7	0.97	Highly reliable

T-test comparing means for H&S prevention measures aligned with monetary and non-monetary incentives

Respondents were asked to indicate how important the provision of both monetary and nonmonetary incentives were in achieving the health (HIV/AIDS) and safety targets, where 1 = unimportant, 2 = little important, 3 = somewhat important, 4 = important, 5 = very important, 6 = extremely important, 7 = of utmost importance, and U = unsure. A paired-sample t-test was conducted to compare scores on various health and safety prevention areas. Results are reported in Table 4.4 and Table 4.5. There was a statistically significant increase in scores for selecting candidate on the basis that they have H&S plan from MI (M = 4.56, SD = 2.08) to NMI (M = 4.80, SD = 1.89), df = 146, p = 0.05 (two-tailed). The eta squared statistic of 0.03 indicated a small effect of size. Also, there was a statistically significant increase in scores for integrating H&S plan in design from MI (M = 4.67, SD = 1.99) to NMI (M = 4.93, SD = 1.80), df = 147, p = 0.03 (two-tailed). The eta squared statistic of 0.03 indicated a small effect of size. Furthermore, there was a statistically significant increase in scores for the programme for counselling and testing from MI (M = 4.25, SD = 2.03) to NMI (M = 4.46, SD = 1.98), df = 145, p = 0.03 (two-tailed). The eta squared statistic of 0.03 indicated a small effect of size.

Table 4.4 Paired samples statistics

Pair		Mean	N	St Dev	Std. Error Mean	Eta squared
1. The participants to the project selected on the basis that they have H&S plan	MI	4.56	147	2.08	0.17	0.03
	NMI	4.80	147	1.89	0.16	
2. The integrating H&S plan in design	MI	4.67	148	1.99	0.16	0.03
	NMI	4.93	148	1.80	0.15	
3. The induction programme on H&S before commencing the project	MI	4.90	149	2.02	0.17	0.01
	NMI	5.09	149	1.79	0.15	
4. Worker training on H&S	MI	4.91	149	2.01	0.17	0.02
	NMI	5.11	149	1.84	0.15	
5. The programme for counselling and testing of diseases	MI	4.25	146	2.03	0.17	0.03
	NMI	4.46	146	1.98	0.16	
6. The compliance with H&S standards	MI	5.13	149	2.00	0.16	0.00

	NMI	5.21	149	1.78	0.15	
7 The achievement of H&S requirements	MI	5.07	149	2.01	0.16	0.01
	NMI	5.26	149	1.80	0.15	

However, there was no statistically significant increase in scores for induction programme on H&S before commencing the project although mean scores increased ranging from MI (M = 4.90, SD = 2.02) to NMI (M = 5.09, SD = 1.79) , df = 148, p = 0.17 (two-tailed). The eta squared statistic of 0.01 indicated a small effect of size. Worker training on H&S had scores ranging from MI (M = 4.91, SD = 2.01) to NMI (M = 5.11, SD = 1.84), df = 148, p = 0.11 (two-tailed). The eta squared statistic of 0.02 indicated a small effect of size. The compliance with H&S standards had scores ranging from MI (M = 5.13, SD = 2.00) to NMI (M = 5.21, SD = 1.78), df = 148, p = 0.58 (two-tailed). The eta squared statistic of 0.00 indicated a small effect of size. The achievement of H&S requirements had scores ranging from MI (M = 5.07, SD = 2.01) to NMI (M = 5.26, SD = 1.80), df = 148, p = 0.16 (two-tailed). The eta squared statistic of 0.01 indicated a small effect of size.

It is evident that non-monetary incentive mean scores were higher than monetary incentives in all factors. Non-monetary incentives are mostly preferred, implying construction participants may be motivated by factors other than money to achieve project goals.

Table 4.5 Paired Samples Test

Pair		Paired Differences					T	df	Sig. (2tailed)
		Mean	StD	Std. Error Mean	95% CI of the Difference				
					Lower	Upper			
1. The participants to the project selected on the basis that they have H&S plan	MI & NMI	-0.25	1.49	0.12	-0.49	-0.00	-2.00	146	0.05
2. The integrating H&S plan in design	MI & NMI	-0.26	1.48	0.12	-0.50	-0.02	-2.16	147	0.03
3. The induction programme on H&S before commencing the project	MI & NMI	-0.18	1.65	0.13	-0.45	0.08	-1.39	148	0.17
4. Worker training on H&S	MI & NMI	-0.21	1.57	0.13	-0.46	0.05	-1.62	148	0.11
5. The programme for counselling and testing of diseases	MI & NMI	-0.21	1.21	0.10	-0.40	-0.01	-2.05	145	0.04
6. The compliance with H&S standards	MI & NMI	-0.07	1.63	0.13	-0.34	0.19	-.554	148	0.58
7. The achievement of H&S requirements	MI & NMI	-0.18	1.58	0.13	-0.44	0.07	-1.40	148	0.16

Discussions

From non-monetary incentives point view, findings show a factor related to a construction project that achieved H&S requirements scored higher (M=5.26). From monetary incentives point of view, a factor related to the compliance with H&S requirements had a mean score of 5.13. Findings also suggest that both monetary and non-monetary incentives are regarded as important rewarding mechanisms to compel project participants to achieve health (HIV/AIDS)

and safety objective. Hence, there is a common understanding, although not balanced, that the prevention is better than cure. In fact, Mthalane, Othman and Pearl (2008:5) complain that unsafe and unhealthy working conditions still have claim an economic toll at the start of the 21st century. By acting proactively, H&S prevention cost will far outweigh the remedial H&S failure cost. In addition, Kyereh and Hoffman (2008:45) indicate that HIV/AIDS results in increased costs for a company in the form of insurance cover, retirement fund claims, health and safety claims, medical assistance, increased demand for training, recruitment and funeral costs.

Given the statistical significance difference found in some factors, this suggests monetary incentives should be offered towards the compliance with H&S standards, the achievement of H&S requirements, and the induction programme on H&S before commencing the project.
However, it is not evident at what extend clients are prepared to go extra mile to cater in H&S in construction project budget. It could be argued that the provision of monetary incentives may compromise health and safety ethics. However, monetary incentives may be administered in a strict way to achieve health and safety targets. For example, Dean (2010:38) suggests that the employers who implement prescribed health and safety improvements in their workplaces would receive a rebate on premiums. In the short-run, both monetary and non-monetary incentives may work well to achieve H&S prevention measures. The t-test results also showed a statistical significant increase from monetary incentive to non-monetary incentives in relation the programme of testing and counselling and testing diseases. Given that construction firms are profit driven, the task of testing HIV/AIDS and counselling affected workers may distract them from the core construction business. While health cases may be referred to appropriate state service provider, construction firms should create a working environment enabling worker to attend testing and counselling sessions as the need may arise. CIDB (2003:2) proposes 90% of construction workers should attend HIV/AIDS awareness programme.

The statistical significant increase was also found on the selection of participants into the project based on H&S plan, and the integration of H&S in design. Typically, these tasks which are done at pre-construction stage. Impliedly, the construction still ignores the importance of integrating H&S plan at early stage of construction project process. It seems a great importance is attached on construction stage rather than considering the importance and H&S throughout all stages.

CONCLUSIONS

Currently, the findings show the mind-set of the construction industry is more inclined into offering non-monetary incentives than monetary incentives. Findings reveal the current standoff of the construction industry attaching higher importance on the provision of nonmonetary incentives than monetary incentives in achieving H&S prevention measures. Therefore, these findings imply more has to be done to change the mindset of construction participants to move towards a proactive procurement environment enabling the incorporation of monetary incentives to achieve H&S prevention measures. Therefore, there is a need to bridge the gap such that the construction industry understands that both monetary and non-monetary incentives are equally important. It is suggested that long-run intervention measures

as a continuous improvement can be initiated from various construction stakeholders encouraging them to initiate both monetary and non-monetary incentive driven procurement environment.

RECOMMENDATIONS

Given the exploratory nature of the study, data gathering was confined to the view of contractors and professional practitioners. Further studies are required to get the view of both private and public clients. Further studies should focus on workers involved into actual activities which expose them to H&S hazards. Where construction projects are identified having high risk H&S hazards, both monetary and non-monetary incentives should be incorporated into procurement documentation.

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Zero Energy and Retrofitting

CONCEPTUALIZING A SYSTEM FRAME WORK FOR RETROFITTING EXISTING BUILDINGS IN SOUTH AFRICA

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Keywords: complex adaptive system theory, energy efficiency, existing building, retrofitting.

ABSTRACT

Designing energy efficient retrofits for buildings will bring about environmental, economic, social, and health benefits. However, selecting specific retrofit strategies is complex and requires careful planning. The reported study attempts to provide insights into how the retrofit phenomena can be understood and addressed within a social-technical context. A proposed way of understanding the complexities of retrofitting an existing building with the use of the complex adaptive system theory approach is highlighted and discussed in the paper. The proposal screen buildings for potential improvements that support the development of retrofit strategies, which mitigate carbon emission. The model reveals the relationship between different components of building energy retrofit projects. The implications of the proposed conceptual framework for future research are discussed.

INTRODUCTION

As a result of global warming and limited natural resources, countries around the world are keen on reducing carbon footprint (National Refurbishment Centre, 2012). The clamor for the built environment to contribute to reducing energy consumption has necessitated researchers to explore various dimensions of curbing the rate of carbon emission through effective energy retrofit. Due to its many constraints and limitations, retrofitting buildings for energy efficiency is considered an interdisciplinary process where several factors need to be involved (Godwin, 2011). These factors influence the type and extent of the project, making each retrofitting project a unique and complex optimization problem.

The term energy retrofit is defined as the installation of individual or multiple energy efficiency measures to an existing building (Langston, Wong, Hui and Shen, 2008). According to Lombard (2012), existing buildings in South Africa are responsible for 3.5% of final energy consumption, with the majority of the energy being used to power heating, ventilation and air conditioning (HVAC) systems, lighting and office equipment. The South African Property Owners Association (SAPOA) (2010) posits that electricity is the primary component contributing to the running

costs of buildings and the cost of electricity will inherently have an impact on the overall profitability of their companies. There are a number of ways in which one could reduce energy consumption within a building. The simplest way to ensure that buildings consume less energy is to build new sustainable buildings. However, for existing buildings, retrofitting is the way forward. Energy retrofitting is a fairly new concept, which needs to be understood and further explored within the South African context.

The historic availability of relatively cheap electricity within South Africa is one of the primary reasons why existing buildings have been designed and built in such a way that they have performed poorly regarding energy consumption (Lombard, 2012). It is generally accepted by the property industry that retrofitting of a building will result in a number of associated benefits (Clinch and Healy 2010). Kurul (2007) posit that adopting this process could significantly contribute to the mitigation of climate change by reducing CO emissions. But the challenges$_2$ emissions. But the challenges due to its complexities need to be overcome. In addition, various attempts at energy retrofitting have been documented across the globe in the form of working documents, guidelines and academic publications. Yet, some gaps have been established after a review of these documents pertaining to energy retrofit. The gaps identified form the bedrock for this research. Table 1 the gaps in energy retrofit.

TABLE 1: Gaps in retrofitting existing buildings

Gaps	Authors
Non-interaction of the social elements of the socio-technical system with the technical aspects.	A study by Swan and Brown (2013) reveals that the successful retrofitting of buildings to improve energy performance is not simply a technological challenge. It is a complex socio-technical problem that needs to be addressed in a co-ordinate way, utilising skills and knowledge from a range of industrial, technical and social backgrounds (Swan and Brown, 2013). Amongst the complex social-technical challenge are retrofit technology, human factor, building specific information, client resources and expectation and other uncertainty factors as observed by (Ma, Cooper, Daly, and Ledo, 2012).
	Performance gap issues in housing retrofit projects are a major challenge in the field. Closing the gap in such projects could potentially make a novel contribution to major reduction in energy consumption by delivering design predictions (Bayat, 2014).

	Inadequacy of retrofit measures is identified as one of the major retrofit challenges as the effectiveness of technological measures is unreliable (Davies and Osmani, 2011). Swan, Ruddock and Fitton (2013), conduct a detailed investigation assessing the effectiveness of retrofit measures, which validates such perceptions. Dowson, Poole, Harrison and Susman (2012) share the same view, suggesting that retrofit measures using technology 'may only be half as effective as anticipated'. This indicates that the retrofit measures (technology alone) are to a certain extent unreliable, which effectively has a direct impact on the efficiency of
	retrofit design integration.
Organisational culture/behavioural problem	Koshman and Ulyanova (2014) opined that human beings are an integral part of the energy management system but much energy saving measures focus only on technologies and appliances. Karvonen (2013) concluded that effective energy efficiency upgrades can be achieved through the development and realisation of customized solutions to each house through facilitated engagement between occupants, housing providers, and construction professionals).
	A study conducted by Hermelink (2005) reveal that technical measures alone in retrofitting do not lead to the attainment of the forecasted results. They argue that human factors should be considered during retrofitting to bring about the desired levels of effectiveness.
Change management problem	A significant impediment to the implementation of long-term energy retrofitting plans is the inability to cater for the behaviour of building occupants (Natural Resources Canada, 2015). Behavioural change, although an intangible measurable can have a significant impact on the ultimate success on an energy retrofit (Fulford 2011).
	According to Natural Resources Canada (2015), energy retrofit management is more about change management than engineering and buildings are dynamic environments that must evolve to maintain the value they provide to their owners and occupants. According to Karvonen (2013), realising significant reductions in energy demand it is imperative to incorporate changes in stakeholders' understanding and social practices (habits, perceptions and motivations) when coupled with physical interventions.

Source: Authors (2018)

Among the most common themes identified in building energy research, human factor has been found as a major factor (Swan and Brown, 2013). Despite this observation, current retrofitting measures have continued to down play the level of consideration accorded to this factor. There is a need to evolve a mechanism by which industry stakeholders will be better-informed about effective energy retrofit. There are few ways to address this gap such as; understanding the variables/elements that made up an effective retrofitting; understanding the dynamics of the constituent's elements, analyzing the relationship between the elements and adapting the elements in such a way to aid towards effective retrofitting.

Consistent with research from other scholars, there is empirical evidence to support a positive link between complex elements that influence effective retrofitting (Ma, Cooper, Daly, and Ledo, 2012). The relationship has been established in building energy research and its

consequence is recognized as crucial indicators for improved building energy retrofit. The analysis and integration of this key element (socio-technical) of retrofitting has been shown to be generally predictive of effective retrofitting (Ma et al, 2012), but more research is needed to identify and integrate the element that are associated with the effectiveness of building retrofit (Karvonen, 2013).

The mechanisms of effective retrofitting within existing buildings is not well understood, especially when it concerns integration of socio-technical components (Karvonen, 2013). In this context, this research seeks to make an attempt at understanding the retrofitting phenomenon through a socio-technical system perspective. Pertaining to the social aspects of this sociotechnical systems perspective, this study seeks to explore the influence of human factors associated with building occupants on the design and delivery building energy project.

LITERATURE REVIEW

A growing trend in the social, technical and behavioral science research is to think about and attempt to understand specific research problem from an interdisciplinary view (Frodeman, 2010; Jacard and Jacob, 2010). A theoretical framework is the "blueprint" for an inquiry (Frodeman, 2010). As such, this section briefly highlights the theories influencing the study.

SYSTEM THINKING THEORY

Systems thinking can be used in solving complex problems that are not solvable using conventional reductionist thinking (Mele, Pels, and Polese, 2010).Since Aristotle's posit that knowledge is derived from the understanding of the whole and not that of the single parts, researchers have been struggling with systems and parts in terms of their contents and their relative dynamics (Mele et. al, 2010). This historic effort evolved during the last century into "systems theory" (Bogdanov, 1922, 1980: 182; Von Bertalanffy, 1968; Lazlo, 1996; Meadows, 2008). In the same vein, Checkland (1981; 1999)affirmed that a system thinking theory usually consisted of a set of distinct elements linked together to form a whole, showing, in the process, properties of the whole instead of properties of its component parts. A system can be defined as an entity, which is a coherent whole (Ng, Maull and Yip, 2009) such that a boundary is perceived around it in order to distinguish internal and external elements and to identify input and output relating to and emerging from the entity.

Generally, retrofitting exercises are complex, contradictory and iterative. Yet its constituent elements are considered in relative isolation. The creative response is to identify the key elements and their inter-relationship that helps explains building energy retrofit. It has also helped in providing a new approach that allows synergetic interaction between different elements, thus increasing the possibility of innovative, trans-disciplinary solutions to retrofitting issues. The concept of system thinking perspective was reviewed based on the premise of associated elements and the complexity construct involved in the delivery of effective building retrofit, especially as it concerns those being delivered through the government.

CHAOS THEORY

Various scholars in diverse fields (Ayers, 2007; Barton, 2014; Elbert, et al. 2014; Eve, et. al, 2011) contended that instability, dynamicity, evolution, and change from the very nature of every system. This paper argues that such traits are embedded in the system characteristics. Systems are always subject to constraints, threats, dynamics, imposed changes, and voluntary changes (Ayers, 2007).

The proposition of chaos theory is that systems are located in the hub of chaotic galaxy. The interactions of the systems and their components generate outcome, but the outcome is neither unpredictable nor the direction of the movements subsequent to the initial moves. This notion applies to systems that have greater degree of complexity and dynamicity. The theory contends that not all systems obey randomness; some systems can be defined and bounded by mathematical functions, depending on the controllability of initial and subsequent conditions (Townsend, 1989). Across different disciplines, chaos theory and its concepts are being used by researchers ranging from information technology, engineering, economics, social sciences, cognitive, developmental and clinical psychology(Bonting, 2005; Eve et al., 2011; Freeman, 2007: Guastello, Koopmans, and Pincus, 2009).The consideration of chaos theory involves understanding the interdependencies, interrelationship and interconnections between technology (e.g., tools and equipment), work tasks and processes, and human factor (Challenger and Clegg, 2011).

An important implication of this approach to retrofitting systems is the understanding that changes to one aspect would undoubtedly affect the other aspect (Challenger and Clegg, 2011). Series of concept guiding retrofitting include simple design informed by the end-user, congruence between all parts of the system and with organisational behaviourism, integrated task perspectives and the enabling of local experts to problem-solve and adapt systems appropriately (Clegg, 2010). Using a chaos theory perspective to understand existing systems in the energy management space helps to identify disconnects between technology and human factors that are systemically supported by the retrofitting design (Tucker and Topi, 2013).A research study by Tucker and Topi(2013) concurred that chaos theory is premised on the interdependent and inextricably linked relationships among the features of any technological object or system and the social norms, rules of use and participation by a broad range of human stakeholders. The review of chaos theory in this study was informed to probe deeper into the interaction between human factors, technology, and using such knowledge to bring about synergy in the whole system.

COMPLEX ADAPTIVE SYSTEM THEORY

Retrofit addresses issues from the simple (with well-known cause/effect links) to the highly complex (webs and loops of cause/effect with unpredictable, emergent properties). Yet there is no conceptual framework within its theory base to help identify approaches appropriate to the level of complexity. The default approach favours reductionism (the assumption that reducing a system to its parts will inform whole system behavior). Such an approach can yield useful knowledge, yet is inadequate where issues have multiple interacting causes, such as social and technical determinants of effective energy retrofit. To address the complexities of retrofitting, there is a need for a conceptual framework that helps choose action that is

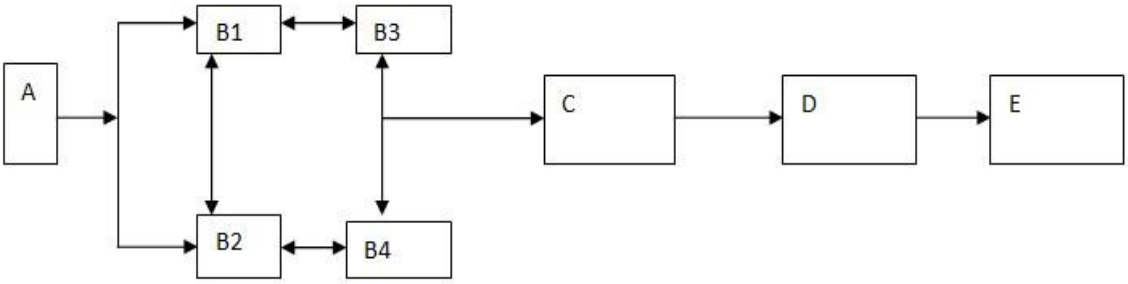
appropriate to context. These problems prompt the use of complexity science-the study of Complex Adaptive Systems (CAS). Complexity results from the inter-relationship, inter-action and inter-connectivity of elements within a system and between a system and its environment (Chan, 2011). According to MacLennan (2012), a complex adaptive system is a collection of individual system with freedom to act in ways that are not always totally predictable and whose actions are interconnected so that one system's actions changes the context for other system.

The CAS model are complex in that they are dynamic networks of interactions, and their relationships are not aggregations of the individual static entities, i.e., the behavior of the ensemble is not predicted by the behavior of the components. They are adaptive in that the individual and collective behaviour mutate and self-organize corresponding to the change initiating micro-event or collection of events (Gupta and Anish, 2012; Miller, John and Scott, 2007; Mitleton-Kelly, 2012).The CAS model is a complex macroscopic collection of relatively similar and partially connected micro-structures formed in order to adapt to the changing environment and increase their survivability as a macro-structure(Gupta and Anish, 2012; Mitleton-Kelly, 2012;MacLennan, 2012).The urgency to address critical issues such as carbon emission, involving the social and technical determinants of building energy retrofit calls for this study to engage with complexity science. As Thovhakale, McKay, and Meeuwis (2013) make it clear that retrofitting is an example par excellence of a chaotic and complex system: To resolve these traps this means the following variables in chaotic and complexity domain in the context of effective retrofitting must be identified and resolved. In the study of Ma et al, (2012), they concur that effective retrofitting can be influenced by the following complex elements: human factor; retrofit program; end-user energy management; material culture and best practice of retrofitting.

Therefore, maximising the potential for carbon emission reduction requires much deeper understanding for how different factors interact in existing buildings. A study by Kelly (2013) indicate that human factor is as important as the physical characteristics of a building in influencing energy use, and those carbon emissions from building are most sensitive to internal temperature changes, largely dependent on human behaviour. By understanding the interaction between socio-technical variables, then the complexities of retrofitting and the relationships affecting energy use will be untangled (Shipworth, 2000; Kelly, 2013). The phenomenon 'building energy retrofitting' can be understood as the phenomena of complex adaptive systems. For the purpose of this study, the approach to industry innovation and learning adopted for the delivery of building energy retrofit is arguably situated in CAS.

The CAS provides the platform for unravelling the complexities, chaotic nature, relationship, cooperation, continuous improvement, dynamism, opportunities and adaptability for further innovation in all critical segments of energy retrofitting processes. The entire system of retrofitting can be seen as a network of relationships and interactions, in which the whole is very much more than the sum of the parts. A change in any part of the system, even in a single element, can result in reactions and changes in associated elements and the environment. Therefore, the effects of any one intervention in the system cannot be predicted with complete accuracy because the system is always responding and adapting to changes and to the actions of individual elements. In practice, this idea urges recognition of the multiplicity of the associations that shape effective retrofit. A complex adaptive systems framework for effective retrofitting would encompass the energy retrofit best practice, human factor, end user energy

management, retrofit program and material culture. Furthermore, these relationships are non-linear and causation is multidirectional, so that simple causal relations between dependent and independent factors are difficult to isolate. Causes are also outcomes. For example, people's adoption of technology will be as a result of end-user energy management which will in turn help in reducing the dissipation of energy in the building. The study focused on the way in which interventions in the system affect effective building energy retrofit. In the proposed conceptual framework provided in Figure 1, a detailed mapping of such linkages, in order to explore, understand, resolve and as well adapt the complexities of retrofit systems are shown.



Where A = identification of key elements involve in energy retrofit of an existing building

B1 = Human Factor

B2 = Retrofit programme

B3 = Material Culture

B4 = Best practice for building energy retrofit/ end user energy management

C = Complex Adaptive System for retrofitting

D = Improved delivery for BERP

E = Carbon emission reduction

Figure 1: Conceptual framework (Source, Author, 2018)

The proposed conceptual framework was adapted to theoretically represent components of the effective energy retrofit. Specifically, the model places effective energy retrofit and carbon emission reduction at the centre, internally influenced by five broad areas: human factors (social viewpoints and attitudes towards energy use), material culture (retrofit technologies and building fabric), retrofitting program, end user energy management and energy retrofit best practices. The proposed model illustrates how a holistic approach can be adopted to address optimal energy savings in an existing building, as opposed to simply targeting one area. By investigating and improving the areas outlined in the framework, the study will help in improving delivery of building energy retrofit projects in South Africa.

This conceptual framework has number of implications, as a unique model explaining the sociotechnical issues of a typical retrofit project mediated by the CAS. In addition, the research will identify how CAS of building energy retrofit is formed from the constituent elements. Finally, in order to achieve the predictive validation of the model, relationship of all the components will be examined through empirical investigation, which will reveal the strength of their association both individually and collectively.

CONCLUSION

After many years of building energy retrofit research, it is unclear how building energy retrofit projects are delivered against the backdrop of socio-technical barriers. To address this gap, this research argues that the complex adaptive system model is the key to unravel the dynamics surrounding these complexities. In addition, this research identifies the theoretical formation of the building energy retrofit of an existing building. It proposes a framework to examine the mediated relationship of the constituent element involved. The research is useful for facility managers, client, property owners, and retrofit-practitioners keen on tackling associated challenges of embedded in retrofit projects.

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IMPROVING THE INTEGRATION OF FUNDING PRIORITIES WITHIN THE DECISION-MAKING PROCESSES OF DOMESTIC RETROFITS IN SCOTLAND

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Keywords: Ageing population, domestic housing, energy efficiency, sustainable decision-making.

Abstract

There is a requirement to address the needs of the most at risk individuals in society through robust policies designed to improve the energy performance of buildings and safeguard the wellbeing of the elderly from the known vulnerabilities of their immediate and surrounding environment. Due to reduced funding and the misalignment of priorities there is a need to evaluate the quality control within government retrofitting standards and processes to prevent unintended consequences. It is recognised that due to the complexity of the agenda, holistic integration across a range of service providers is required. In response this research examines the relationships between design and implementation within real-world practice to determine and understand the appraisal procedures in housing and any consequences that arise. This research presents the findings of a preliminary study, where research was conducted through a series of in-depth interviews conducted with key stakeholders within government, social care and the retrofit industry, exploring the extent to which the requirements of an older person's health and wellbeing are holistically being addressed during the retrofit of domestic buildings. The study concludes by posing a series of research questions, providing an agenda for future research and presents a synthesis of insights on practical and policy implications originating from the analysis on decision-making and management.

INTRODUCTION

Domestic energy use represents 30% of total energy use in the UK, making it essential in achieving national carbon reduction targets (Sharpe and Shearer, 2012). Housing holds a fundamental relationship to physical and mental health; creating either long-term security or insecurity for the resident. However, the lack of decent dwellings is recognised as a key future challenge to the economy, environment and society of the UK (DCLG, 2006). This deficit is particularly important due to economic growth and advances in health care, meaning people are living longer than ever; with 25% of the population in Europe expected to be over 65 by 2020 (Boerenfijn et al. 2018). In Scotland, the devolved government has set ambitious carbon reduction targets and drastic action is required, presenting the challenge of achieving this whilst preventing unintended consequences. Therefore, there is a need to examine the expertise and processes surrounding Scottish Government retrofit programmes to determine the effects of the current retrofit agenda on the health and wellbeing of the elderly. Presented are the findings on the analysis of nine key stakeholders' expert views through a constructivist grounded theory approach to determine the short comings of funding cuts and requirements for a holistic approach within governance for the retrofit agenda. The findings from this study

will establish research questions which will provide the foundation for future research in this area.

LITERATURE REVIEW

The need for retrofit

Over 21 million dwellings in the UK were built before 1980, therefore the majority of housing stock pre-dates energy efficiency standards; creating widely non-decent living standards across the UK. The role of dwellings in reaching ambitious climate change targets and protecting the wellbeing of the vulnerable should not be underestimated, with an estimated 70% of the existing housing stock still in use by 2050 (Fylan et al., 2016). Furthermore, in addition to having one of the most inefficient housing stocks in Europe, the
UK has the highest number of householders in fuel poverty at 11% in 2014 (Gupta and Gregg, 2018). However, fabric energy efficiency retrofits have the potential to deliver 60% reduction in CO_2 emissions, but require an estimated expenditure of approximately £200 billion. Although a substantial investment, this is seen to be one of the most cost effective solutions, and the prioritised approach by the government to decarbonisation (Davies and Oreszcyn, 2012).

The importance of housing

Most of human life is spent in buildings. This is particularly imperative to the elderly population whom are estimated to spend 70-90% of their time at home. Therefore, the level of value attributed to the built environment with regards to human health and happiness should not be underestimated. However, this does not mean that all experiences are positive. Housing is one of the most fundamental conditions that determine living standards such as quality, comfort and wealth and is considered imperative for achieving sustainable development goals (Saldaña-Márquez et al, 2018). The housing sector requires great levels of attention, not only because of its economic and ecological importance, but also due to its enormous social value; impacting social cohesion, trust, a sense of belonging, and therefore, the wellbeing of the population. Moreover, maintaining a warm home is considered a basic need, and the inability to uphold this can have negatively impact mental and physical health (Bullen and Kearns, 2008).

Ageing population

The rationale for focusing on the elderly arises from both policy and research. Within the UK's fuel poverty strategies, the elderly, alongside the disabled and low-income families, are recognised as the most vulnerable within society. The political and public dialogue surrounding fuel poverty has primarily focused on older people, with more policy instruments targeted within this group (Gillard et al., 2017). Furthermore, the elderly have become the 'hallmark' of the extreme fuel poor, due to higher heating requirements and declining incomes (Walker et al., 2017). Maintaining a healthy ambient environment can be challenging. Whilst the poorest individuals are the most susceptible to fuel poverty, they have the least resources or power to invoke the necessary change (Krieger and Higgins, 2002). Moreover, poor housing conditions

have been greatly associated with mental health issues resulting in problems such as social isolation ensuing from reluctance to hold social gatherings due to feelings of embarrassment or helplessness (Bullen and Kearns, 2008). There is a need for older people to invest in, understand and trust energy saving initiatives, allowing them to become empowered and informed in their decision-making whilst acting as a preventative and defensive method against fuel poverty (Walker et al., 2017).

Ensuring quality in retrofit practice

Given the level of public investment in housing, it is vitally important that building performance is systematically evaluated throughout the retrofit process to both the national climate change agenda and the everyday lives of people. Building Performance Evaluation is crucial in assessing palpable evidence of the building performance and in identifying the factors leading to actual consumption (Sharpe, 2012). However, it is increasingly evident that when evaluation occurs, there is a substantial gap between predicted and actual energy use; potentially significantly undermining carbon reduction targets and timelines within public policy (Sharpe and Shearer, 2014). The post hand-over period is often neglected and seen as a nuisance, with many not having an appetite for or lacking the funding required to learn about how the building performs in-use. However, learning how buildings perform is essential within the systematic improvement of the energy sector (Way and Bordass, 2005). Furthermore, Post Occupancy Evaluation (POE) is often regarded with suspicion and hostility, creating friction amongst stakeholders (Meir et al., 2009). Nonetheless it is one of the fastest and more predictable sources to improve the environmental and economic performance of the built environment, whilst achieving greater user satisfaction (Meir et al., 2009). This fragmentation has stunted POE development. However national and local government should be promoting greater design and building practice, reducing rework and revisits, whilst increasing commercial intelligence for future use.

Known consequences of retrofit

Without rigorous quality assurance methods, unintended consequences can arise from the retrofit of homes. Within the UK's Health Housing and Safety Rating System overheating is one of the defined hazards, with high temperature increasing cardiovascular strain and trauma and increasing the risk of stroke and mortality. Whilst overheating can be minor to some, the risks are greatly increased for vulnerable groups such as the elderly. There is a growing awareness that overheating is a significant problem, which will increase with a warming climate and a move towards greater energy efficient buildings (Morgan, et al., 2015). As a resolution to this, Mechanical Ventilation with Heat Recovery (MVHR) have been installed within many domestic buildings. MVHR can influence air quality, moisture load and temperature. However, as a relatively new technology there have been issues with design, installation, commissioning and use (Foster et al., 2016). Whilst there are benefits to using this system, it is crucial that there is careful design, maintenance and user-interaction as misuse presents a tangible risk to the quality of the ambient environment, the health of the resident and a potential increase in energy consumption (Sharpe and Shearer, 2012). Internal Air Quality (IAQ) is a vital component, but often neglected. Achieving IAQ is crucial for health and wellbeing and can result in

detrimental energy performance from users misunderstanding of systems, such as the opening of windows or shutting off systems due to noise (Sharpe, 2012). An absence of adequate ventilation can result in detrimental effects such as mould growth and toxin build-up resulting in fatigue and respiratory problems. Moreover, it encourages a proliferation of microorganisms and house dust mite populations (Way and Bordass, 2005). The lack of engagement and understanding between occupants and their ventilation systems poses a great risk upon health, which must be address through design and legislation. This lack of coordination between those implementing these changes and the individuals living in altered environments displays a key problem, one which must first be tackled at governance level through improved decision-making, then implemented throughout the system to create a holistic approach to domestic retrofit practice.

Governance and retrofit

Historically, building regulations focused on the health, safety and welfare of building occupants, emerging in response to widespread illness and death due to unsanitary conditions and significant hazardous events (Meacham, 2016). Building regulations have been the primary mechanism to affect change within the standards surrounding the built environment. Although these standards have significantly developed over recent years, it is evident that this is not being translated into tangible energy savings. Furthermore, building regulations focus primarily on new build construction, not upgrading the existing building stock. Existing buildings have a significantly worse energy performance than new builds and are not subjected to the same regulatory requirements (Sharpe, 2012). This fragmented regulatory approach has led to unpremeditated consequences such as health hazards from flammability of thermal insulation materials, as witnessed in the Grenfell disaster in London in 2017. The challenges facing the health and wellbeing of the population are intensified when addressing existing building stock due to the reduced regulatory oversight and economic capacity of the sector (Meacham, 2016). Therefore, due to the complexity of delivering this agenda, there is a need to investigate the decision-making and quality assurance within government retrofit, which target the most vulnerable of individuals within society to determine the impacts of funding cuts on the population receiving energy efficient improvements within their homes.

METHODOLOGY

The aim of this study is to explore the extent to which funding cuts within government retrofit programmes impact the health and wellbeing of an ageing population under a constructivist grounded theory approach. This research takes an exploratory approach to understanding with a view to allowing compilation of recurrent interpretations and data to help shape later stages of research.

METHODOLOGICAL APPROACH

Grounded theory is defined as the inductive conceptualisation of data through a systematic, constant comparative method of simultaneous data collection and analysis to establish theory

(Charmaz, 2014; Glaser and Strauss, 1967). In selecting which variation to use, the philosophical and practical approach of both classical and constructivist grounded theory were considered for this research. Classical grounded theory is often defined as positivist; seeing the researcher as impartial from the participants (Glaser and Strauss, 1967). Conversely, within constructivist grounded theory, the researcher is central with their participation and seen across data collection, analysis and theory construction creating a relativist and pragmatic approach towards the methodology (Charmaz, 2014). Within classical and constructivist, data collection and analysis are systematic and iterative, limiting theory generation until themes and relationships are developed (Charmaz, 2014; Glaser and Strauss, 1967). In classical grounded theory the use of literature was utilised only after completing analysis to prevent contamination of research findings and reduce influences and creating preconceptions. Contrastingly, Strauss and Corbin (1990) argued for professional literature to be reviewed before data collection begins and throughout analysis and theory generation, however the researcher was to remain objective, whilst Charmaz (2014) saw an abductive process where the research becomes active. Where constructivist grounded theory seeks active participation in interviews, classical considers involvement as a disturbance, using analysis and theoretical sampling as platforms for exploration (Glaser and Strauss 1967). When grounded theory is combined with a constructivism paradigm, it embraced the existence of multiple individual realities, ensuring meaning is co-constructed to produce an interpretation adept in explaining these realities. Having considered both approaches and the requirement for philosophical compatibility between researcher and methodology, constructive grounded theory was selected. Firstly due to its abductive reasoning, creating a logical inference to find the most likely explanation from data presented. Secondly, the interaction between researcher and participant suited the researcher's approach having had experience working within the energy industry; restricting bias. Finally, constructivist allows greater flexibility, with a more literary writing style whilst upholding the analytical process of formal research.

Approach

In line with the methodology, sampling was purposeful. In total 9 industry experts gave written consent to participate; their demographic details are shown in Table 1. The initial participant was selected for their experience and ability to reflect on the interconnections between different retrofit practice in Government. In line with constructivist grounded theory, theoretical sampling began when early concepts and categories emerged, with adaptation of interview questions and adding additional participants to explore gaps in the developing categories (Charmaz 2014).

Table 1: Interview participants

Code	Gender	Stakeholder	Position
C1	Female	Energy	Area Based Scheme Researcher
C2	Female	Health	Nurse
C3	Male	Government	MSP

C4	Male	Energy	Eco Support Manager
C5	Male	Built Environment	Architect
C6	Female	Built Environment	Housing Association Manager
C7	Male	Government/Energy	MP
C8	Male	Energy	Director at Energy Action Scotland
C9	Male	Government/Health	MSP

Data was collected through one to one in-depth interviews. An interview guide containing questions and probes was created to guide the conversation and ensure it remained focused and a neutral approach was adopted, ensuring no leading questions were asked. Each interview began with the same opening question, "*What do you believe are the biggest issues facing housing with an ageing population?*". Initial interviews were open and freeflowing to give participants the freedom to discuss their experiences, with follow-up questions asked when showing statements were made that required further analysis. Later interviews were driven by data analysis and theoretical sampling to expand categories and relationships between them. The interview transcripts were coded word-by-word, then lineby-line, using gerund verbs to stay close to the data (Charmaz 2014). Initial coding involved categorising each line of the written date and initial codes were integrated and refined to develop concepts, categories and sub-categories. Focused coding involved analysis of the most significant or frequent previous codesThroughout this process, theoretical memoing was undertaken, enabling theoretical development and deeper understanding of the data.

DATA ANALYSIS

From analysis, four key themes arose: 'misaligned decision-making', 'removing responsibility', 'creating a holistic service' and 'the need for change' which will be discussed throughout this section. The relationship between these categories present the overarching theme of 'governmentality' with challenges presented by misaligned priorities and poor decision-making impacting negatively on the success of retrofit programmes and impacting the health and wellbeing of an ageing population.

Misaligned decision-making

Ignoring vulnerability

Within different levels of governance and the energy sector, there is a view that the selection of individuals for support is inadequate and misaligned with the goals of protecting those most vulnerable. C3 MSP, begins this dialogue stating, "*all the resources and the low hanging fruit being plucked; chosen by government in dealing with cities and towns first*". This statement refers to the choice between supporting urban and rural areas; the most convenient and inexpensive areas are selected first to receive support, regardless of the known disadvantages

faced within rural locations. Those who are most at risk from isolation and affordable warmth are often forgotten due to disinclination of contractors and increased cost for governance in its application. Exploring this issue in greater depth, C4 Eco Mgmt discussed the economic decisions made which often forsake the most vulnerable due to restrictive qualification criteria for support, "*you have someone on the saving elements of pension credit, they are not much above income support but don't qualify for schemes…it is the whole poverty trap thing, where you are £10 over and have to then pay thousands for insulation measures…the funding is about supporting people who are very vulnerable and they don't…they just miss out*". This statement highlights the difficult in balancing decisionmaking within funding and support allocation; there is no flexibility or discussion of the struggles faced by the elderly which can often result in people already facing challenging living conditions being forced into or allowed to continue to suffer due to a flawed scheme which limits individuals based on numerical values.

Removing responsibility

Disengaging the public

Those applicable for support still face the problem of misunderstanding existing processes and information, resulting in a lack of empowerment and engagement, as deliberated by C3 MSP, "*not everyone has taken up offers of help…there are so many unwanted phone calls…they don't listen to them and they definitely don't take it in…people can get five of these calls a day, they are unsolicited and it is enough to keep people away from doing it*". This is reiterated by C7 MP who states, "*there is a lot of good trade bodies working to improve that but for the ordinary man or woman, finding their way through the maze is often quite difficult…and what is a trusted source?*" These statements display a key misunderstanding on how to appropriately reach out to individuals. With a plethora of different retrofit programmes available, it cuts off engagement and can deter those most in need from receiving the support they require due to a feeling of being overwhelmed. There is a requirement for a guided approach, catered to the needs of different age groups, which appropriately targets them rather than a bombardment of information and communication.

Unsupportive support services

Furthermore, with the complexities of retrofit, there is a need for increased education and more information to improve understanding of how to live with the improved housing conditions. However, currently this does not occur, as stated by C8 EAC Director, "*people are left to their own devices, we might show how to set-up a time but that's it…they will get the meter sorted whilst the person watches, then they will go 'thank you', 'was that ok?' and then leave but there is nothing to check their understanding*". This illustrates that the problem is known, but energy bodies don't have the capacity to combat these problems; there must be a structural change throughout, instigated by government, to ensure there is thorough, easily understood and aptly delivered education post-installation. However, there is a differing view within government, arising from an ideological view surrounding the care of the elderly and communication of information, displayed by a Conservative MP, C7, stating, "*families are needing to identify the risk, family can maybe resolve the risk. Everything shouldn't be burdened to the state, but there are people who have no family and maybe they need a wee bit extra attention*", however an SNP MP, C9, had an opposing viewpoint commenting, "*The government*

obviously has a huge role to play and it is its job to make sure all this stuff is set in place…of course your family has a role to play…they are often as much victims of the situation as the individuals are". The conflicting assessments present a clear opposition between the UK and Scottish government about how to care for their most vulnerable residents, however there is a fundamental need to educate the general public in order for self-reliance can viably occur and to reduce cost upon the state.

Disconnect within government programmes

Furthermore, there appears to be a lack of knowledge and understanding amongst the different government programmes as to what they do and how they interlink. This can be seen from C1 ABS saying, "*there is a system designer for each project, so there will be specifications and things within that of how things should be done properly em…you might be better talking to [colleague] about that because it's his job*" and is further reiterated when asked about collaboration with the health sector, "*there might be, in Home Energy Scotland there is other funding schemes I don't know anything about so again you would be better speaking to them*". These statements display an absence of procedural knowledge and communication, regardless of the close proximity from either within the same room, office or general knowledge of how the different programmes run. Rather than engaging fully with the projects, and engaging with their colleagues, there is an aversion of responsibility onto others which could potentially result in detrimental impacts on those receiving support. Further, an unwillingness to communicate and collaborate with individuals within different projects, limits the capacity for external bodies to do the same and fully engage with the agenda.

Creating an holistic service

Enshrining the importance of energy amongst public and stakeholders

The importance of retrofitting cannot be diminished, cutting across government departments and impacting housing and health agendas, although this connection is not always fully understood. However, this connection must be enshrined within society to protect the health and wellbeing of the elderly. The importance of this can be understood within C5 Architect's analysis, "*news comments about the winter health care crisis which is in part due to people discharged from hospital and returning back too soon because the housing conditions they are returning to are aggravating the very thing they were first admitted to hospital to be treated for*". There is potential for a significant impact from collaboration between health and housing to monitor energy improvements, as C6 HA mgmt states, "*there needs to be communication, tenants coming out of hospital, being discharged… we don't know they were in hospital, I wouldn't expect nurses to phone every single landlord but we could help and I think everywhere you go everyone would say the same thing*". If there was a system in place allowing communication, change could occur, better preparing them for the needs of the vulnerable. With social housing identified as a preliminary model for change, with its greater supply of resources in contrast to the private sector, it allows further financial consideration for future widespread partnership.

Creating a holistic approach within government services

Preferably, when retrofitting the entire dwelling should be inspected and amended to the individuals requirements. However, due to restrictive funding and guidelines the support available can be incredibly constrictive as C1 ABS states, "*the way HEEPS ABS runs misses the whole house approach, particularly in cases where you insulate the walls of the house but the windows are rubbish so heat still escapes…the funding doesn't allow for things like that to be taken into account, it should be factored in but we obviously don't have the budget*". It is disconcerting that problems can be witnessed and ignored, creating potential performance gaps and negatively impacting health and personal economics due to restricting guidelines and budgets. Furthermore, by allowing wider changes when visiting a property it can have a long-term economic advantage as C4 ECO comments, "*if you are looking to future proof against future standards you want to go beyond the current EESH, you want to move beyond one incremental measure, looking at all elements together…there is a cost effectiveness around that*". This statement enforces the acceptance of failures within planning from government retrofits, with incremental modifications and overlooking known problems resulting in re-visitation and potentially negatively impacting government targets. It is apparent that there must be a holistic approach investigating all problems, not solely to create cost savings but for the health and protection of the environment.

The need for change

Improving quality

There is a debate surrounding the effectiveness of existing building regulation and domestic energy rating systems, and the known ability to cut corners to achieve sufficient grading's, as C4 ECO states "*when you are doing external wall measures you don't necessarily need to cover the whole external wall to meet the rating required… you have EESH and SAP targets met but when you actually look at the quality of install there is no way that wall is actually achieving the standard of U-value it says*" and is reinforced by C9 MSP, "*a lot of schemes that were set up by the UK government, there were a lot of holes in the way that was organised, so we've had a lot of issues with unscrupulous businesses taking advantage of people and putting in wall insulation that hasn't properly been through building control*". These statements display the understanding within government and the energy sector that current systems in place are ineffective and inadequate, and contractors are not performing appropriately. There is a necessity for greater quality assurance methods and inspection of work being carried out during a retrofit, to prevent unintended consequences, which is further strengthened by C8 EAC, "*the regulations and testing are not fit for purpose, we need a good testing regime to ensure energy efficiency and warmer homes will not be subjected to the tragedy that Grenfell befell… with Grenfell they made a safe building, unsafe*" showing the extent of this problem and the drastic impacts that can occur from a lack of inspection, and empowerment of the wrong individuals. There must be a robust, consistent and continual inspection process throughout work and post-handover period to ensure the highest level of quality and guarantee the protection of the health of the elderly.

DISCUSSION

The retrofit of existing building stock holds a unique position in its ability to address various social, economic and environmental objectives. There is a need to ensure this practice is progressive and coordinated in order to protect the health and wellbeing of the population. The concept of governmentality proposed by Michel Foucault is used to analyse and examine the strength of actions and influences that underline the decision-making process within Scottish Government retrofit programmes. The triple bottom line of sustainability must be considered to create customer and stakeholder satisfaction. However this is not always implemented in practice, with economic performance often outweighing the importance of social and environmental. Therefore the justification of sacrificing environmental and social welfare to create and improve economic performance of the state must be examined (Gong et al., 2018). There are diverse combinations within governance which define policy agenda which at times compete and at others combine within a collaborative approach. 'Multiple governmentalities' outlines four typologies describing governmentality. Firstly, a disciplinary form in which the population are directed to particular selected norms and values by means to create self-regulation (Foucault, 1997). Secondly a sovereign form, where compliance is sought from top-bottom commands and is reinforced by the threat of punishment. Thirdly, a neoliberal form which will "*act on the environment and systematically modify its variable*" rather than direct subjugation of the people, and finally the governmentality of truth; the truth of religion, revelation and the natural order of the world (Foucault, 2008). However, in reality these contradicting philosophies of government often intertwine and challenge one-another. The state is confronted with the difficulty of maintaining the population's wellbeing and the conflicting view that the state should be austere, constantly pursuing ways to limit its activities to reduce cost and increase independence. The purpose of government is the welfare of the population, the improvement of its conditions and the increase of its wealth, longevity and health (McKinlay and Pezet, 2010). Centred upon population statistics, governmentality recognises that the state's success is measured by its ability to influence the behaviour of the population to improve the welfare of the people. The state justifies these actions by defining them as a mean to expand freedom, beyond the state (Foucault, 1991). However, if retrofit practice is disjointed within its structures and has misaligned decision-making governing it, it prevents useful and accessible knowledge share. If power is held by the people, then they must be empowered to create independence and yield control of their own wellbeing. Furthermore, Foucault claimed that the 'power-knowledge' concept within governmentality diffused outwards from the institutions it was formed by, however if the top lacks the vital knowledge required, then it cannot feasibly trickle down to the bottom (Armstrong, 2015). The top must take ownership, and invest in systems to allow this knowledge share otherwise the neoliberal approach fails and results in greater levels of economic output and suffering of the population; therefore a failure of state. There is an ethical obligation to look after the most vulnerable within society and a key aspect of this discussion is the decision-making surrounding the health of the elderly. Whilst there is a need for the right to autonomy and self-determination, there is a requirement to recognise the network of individuals that negotiate decision-making which removes responsibility from the individual (Carter, 2003). Often vulnerability, and the difficulties faced with understanding complicated technical information dictates that there must be a restructuring of sources and channels to outlay knowledge to create greater

accessibility and widespread comprehension. This includes not only the positives of retrofitting, but potential unintended consequences; creating fundamental behaviour change to permit intrinsic change; improving health, economy and the environment (Hicks et al, 2012). Moreover, Foucault (1982) believed that power may be exercised by collective interests rather than individuals or institutions. This approach argues that power is exercised by people and groups who seek similar results from a common point of interests. Whilst these interests may not always share a common value base, they can share interest in securing a specific outcome such as fuel poverty reduction or greater wellbeing within an ageing population (Clearly and Hogan, 2016). Retrofit practice is highly complex and requires coordination across government, public services and the supply change. Furthermore, the regulation of market involves a number of complex decisions regarding the economy, society and technical regulation; all of which impact the environment. In order to create highly coordinated agreements and processes in place, there must be extensive consultation and information exchange amongst a variety of stakeholders (González, 2017). However, the approach in existence is clearly fragmented. With such complex procedures in place from planning, implementation to post-completion inspection, there is a need for a greater support network which interlinks and creates inclusion throughout; empowering individuals in every level to protect the health and wellbeing of the most vulnerable in society and creating a realignment from profit to people.

CONCLUSION

There is a need for greater collaboration and communication amongst national retrofit programmes and agendas to protect the health of the elderly, preventing unintended consequences. The retrofit of domestic housing is centred around the concept of sustainability; however the ideological prioritisation of economy over people has created an increased pressure on resources, favouring ease and cost cutting over communication, collaboration and efficiency. There is a severe lack of integration and partnership working amongst the government, different retrofit programmes and the people. This absence of understanding amongst programmes of the immediate and wider picture creates substantial barriers and prevents meaningful knowledge share between external bodies and the people. Investment and an altered mind-set from existent neoliberal values are required; initial outlay of economy and time creates a larger investment in the country and will result in the confidence of the population being able to have greater self-reliance, but first there must be resources in place to make this feasible. Social housing and its greater resources and organisation is within prime position to become the forefront of change and sustainable housing whilst creating meaningful change for the most vulnerable. However, there must be a willingness to change and to holistically review the processes in place and resultant implications. Therefore creating a sustainable national retrofit programme that protect the most vulnerable and diminish the impacts of climate change.

Key areas of future research include the exploration of policies and regulations in place to monitor the decision-making of quality assurance of domestic retrofits and the barriers within these; allowing understanding of deep-rooted problems and the impacts created on the energy and constructions sectors, as well as the health of the population. Additionally, there is a need

for significant mixed-method and multi-level exploration that combines large scale analysis of the processes within decision-making from policy development to the iterative inspection process over a long period of time. Further investigation and a comparison is also required of retrofit agendas within Scotland and the UK. This will help determine best practice in place and how the differing political ideologies impact the success of the initiatives and the wellbeing of population across the different countries within the union.

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AN INTRODUCTION TO SYSTEMISED OFFSITE MANUFACTURED AND ENGINEERED TIMBER DWELLING TYPOLOGIES FROM WELSH AND UK FORESTRY SUPPLY CHAINS, ENABLING TRANSITION TO NEARLY ZERO CARBON HOMES IN WALES

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Keywords: Timber Dwellings; Building Performance Evaluation; Architectural Technology; Offsite Manufacturing

Abstract

This paper discusses a Knowledge Economy Skills Scholarship two (KESS2) doctoral project co-funded in collaboration with Woodknowledge Wales, to be undertaken by the first author under the guidance of the other authors. The KESS2 project supports the larger Home Grown Homes project, which is spearheading the use of Welsh timber in construction, undertaken by the four organisations authoring this paper. In 2018, there is an increased need to drive efficiencies in housing supply and also performance with the current and future skills shortages in construction (as articulated in the Farmer Review – Modernise or Die) and is helping to encourage a shift to offsite construction, known as OffSite Manufacturing (OSM). The Welsh Government's £10 Million Innovative Housing Programme introduced in 2017 is helping to massively incentivise the shift to OSM in Wales. The move to OSM and increased systemisation is requiring a profound re-think of how the UK conceives and delivers housing. This PhD will explore the architectural technology detailing of the building fabric and synergy with manufacturing detailing through the use of timber, particularly home-grown timber, for engineered timber solutions, and erection on site; developing typologies for a range of housing markets in wales. The challenges include creating a better understanding of the key technological features required to deliver high-performance systemised timber solutions, with an aspiration to achieve nearly zero carbon homes from 2020 in Wales, and that also provide a healthy environment for their occupants, with zero energy costs. Building on the SuRBe group's expertise in building performance evaluation, particularly in fire and thermal parameter assessment this project will instigate a monitoring programme during manufacture, construction and post occupancy. This paper will be useful for academics, architects, building contractors, housing developers and financial institutions and government agencies evaluating Welsh timber as a construction material.

INTRODUCTION

This paper introduces a Knowledge Economy Skills Scholarship 2 doctoral project funded by Woodknowledge Wales and the European Social Fund, which commences in June 2018; and is being undertaken by the first author (CardiffMet, 2018). The focus of the doctorate is to develop typologies of exterior fabric details for construction or offsite manufacture, with a particular focus on using home grown timber from the UK, and where possible from Wales. This is truly innovative as Wales imports 0ver 80% of the timber used in construction.

OFFSITE MANUFACTURING AND BUILDING PERFORMANCE

In 2018 and in the UK, there is an increased need to drive efficiencies in housing supply and also performance with the current and future skills shortages in construction (as articulated in the Farmer Review – Modernise or Die) and is helping to encourage a shift to offsite construction, known as OffSite Manufacturing (OSM) (Farmer, 2016). The Welsh Government's (WG) Innovative Housing Programme (IHP) introduced in 2017 with £10 million is helping to massively incentivise the shift to OSM in Wales, by funding 100% of the cost of innovation in this area (WG, 2017[a]). Furthermore, by 2020, the WG's target for new affordable dwellings is 20,000 and traditional forms of construction with brick/block exterior walls are both unsustainable from a materials and climate change perspective, but are also slow to construct compared with OSM (Anon, 2017). OSM for housing requires the construction industry to combine design practices from both architectural technology and manufacturing, which is less than apparent in Wales (Offsite Hub, 2018, Chartered Institute of Architectural Technologists (CIAT), 2018). The potential advantages of OSM over conventional construction of housing include quicker completion, greater quality of finish, less defects and better integrated building services (Elnaas and Gidado, 2014). Therefore performance tends to be much nearer to design aspirations than conventional construction techniques (Hetherington, 2016).

One of the greatest problems of new housing is the performance gap where defects in the construction process can impact upon thermal performance and operational energy use for heating once occupied; a major finding of the UK Government's Building Performance Evaluation programme in 2016 (InnovateUK, 2016; Johnston, Farmer, Brooke-Peat, Miles-Shenton, 2014). Littlewood and Smallwood (2015, 2017) and Littlewood et al (2017) go a step further and have demonstrated through the implementation of Littlewood's non-destructive building safety protocol that construction defects also impact upon fire safety performance – as demonstrated by the recent and tragic Grenfell Tower tragedy in 2017 (BBC, 2018[a]). OSM systems in the UK typically use either timber, steel or aluminium as the frame for exterior wall, floor or ceiling panels. Of these materials, only timber is renewable. Performance problems (particularly fire safety) are more important considerations in timber buildings, which is a design, construction and manufacture challenge.

There are many organisations in the UK that supply open panel and to a lesser extent closed panel exterior systems (Structural Timber Association (STA), 2018) and in Wales modern timber construction is predicted to reach 32% of new houses in 2018 (Savills, 2017). Indeed, some of this demand is to meet the WG's aspiration that from 2018 three out of five new homes will be erected with timber (Wood Knowledge Wales, 2017). In Scotland timber construction in 2017 accounted for over 80% of the new-build housing market (STA, 2017). However, Wales imports at least 85% of the timber used in construction from outside the UK, but a strong timber OSM sector in Wales using home-grown timber would reduce dependence on imports and help to catalyse a substantial increase in forestry planting. Wales's forest area is currently 1/3 of the European average (Woodknowledge Wales, 2018[a]). The move to OSM and increased systemisation is requiring a profound re-think of how the UK conceives and delivers housing. The KESS2 project will explore the architectural technology detailing of the building fabric and synergy with manufacturing detailing through the use of timber, particularly home-grown timber, for engineered timber solutions, and erection on site. The challenges include creating a better understanding of the key technological features required to deliver highperformance systemised timber solutions, with an aspiration to achieve nearly zero carbon homes from 2020 and that provide a healthy environment for their occupants, with zero energy costs. With increasing uncertainty in the UK economy post Brexit and the price of natural gas, the predominant fuel for home heating, one way to cut uncertainty and household bills is if all new homes were nearly zero carbon, and therefore zero energy bills for occupants (BBC, 2018[b]). Indeed, this is the aspiration of the Welsh Government from 2020 (WG, 2017[b]). This will be underpinned by evolving a robust and holistic understanding of what is meant by quality – in terms of durability, buildability, energy performance, fire, comfort, sustainability, health and wellbeing, and maintainability. Collectively, these are known as resilience variables hereafter.
The role of WoodKnowledge Wales is to unite the interests of construction clients, Welsh manufacturing and Welsh forestry to support the development and delivery of high performance construction solutions using home-grown timber in a way that maximises the social, environmental and economic benefit to Wales. Therefore, WoodKnowledge Wales needs this KESS2 project to help develop a better understanding of how to design and deliver quality timber systems to meet current and future needs, particular in the context of architectural technology, the science of architecture and OSM. This research is central to WoodKnowledge Wales' desire to champion best practice and deliver leading research in a sector that often lacks the means to deliver high quality research and development.

RESEARCH REVIEW AND METHODOLOGY

Woodknowledge Wales sits at the interface between government and industry, and is pioneering new mechanisms to leverage short-term commercial and political interests to deliver long-term sustainability objectives within the forestry and wood products sectors. This work is critically dependent upon development of new knowledge focused on improving the performance of the timber supply chain. This ambitious project fits well with the core ambition of WKW to develop and communicate the compelling evidence to support the demand led expansion of OSM timber construction in Wales whilst enhancing the business case for forest expansion. The imminent exit from the Common Agricultural Policy provides a once-in-a-

generation opportunity for a land use shift away from grazing to forestry land use in the locations where this can be demonstrated to have net economic and environmental benefits.

In particular, this project will:

- Provide new knowledge around the performance of timber construction.
- Provide new knowledge on how to deliver higher performance solutions within the context of OSM.
- Provide new knowledge on the performance of home grown timber linked to the needs of the OSM industry and inform the development of future forests

Furthermore, key to the successful development of Woodknowledge Wales as a privately funded 'for public good' member organisation, will be the development of highly skilled timber OSM and forest supply chain advocates. Such people can only be developed through education, training and research projects such as this. This research is central to WKW desire to champion best practice and deliver leading research in a sector that often lacks the means to deliver high quality research and development. This in turn will lead to increased income generation opportunities for Woodknowledge Wales.

The project has a series of challenges to investigate due to Wales's wet and warm climate, which is ideal for fast growing short rotation softwoods, as illustrated in Table 1 below. However, fast grown timber is of lower density than slow grown and therefore more prone to movement if it gets wet during the fabrication and installation.

Table One: KESS2 challenges

Academic and Technical 1	How to create robust design/manufacturing details that are both practical and eliminate or minimise the risk of wetting, which means how can the manufacturing process be enhanced to prevent virgin timber from sawmills being stored and then processed in humid or damp conditions. A further challenge of closed panel timber systems is that if construction moisture becomes trapped behind polythene vapour control/air barriers embedded within the panel it may not escape to the outside and could lead to mould growth or fungal decay. This has implications for structural integrity and human health, but is very difficult from a technical perspective to eradicate without dismantling the panels. Indeed, how could the timber systems be designed and manufactured in a way so that they could have their exterior waterproof finishes in place in both horizontal and vertical planes to prevent rain damage on site during erection. Equally, how can the transport and erection of engineered systems be enhanced so that during this process water is not able to collect on surfaces that are later covered with finishing materials and then later causes ingress of moisture problems into the buildings?
Technical 2	How can Wales replicate Scotland and increase the use of home-grown timber in construction to 80%, what types of tree species are appropriate for OSM of closed panel systems, and does Wales need to plant species grown in Scotland, or adapt how the timber grown in Wales is used in terms of the design, manufacturing and erection process?
Academic 2	What is the most appropriate design and manufacturing standard to achieve nearly zero carbon positive homes with home grown timber, is it Passivhaus from Germany?

Academic and Technical 3	Currently only the six public limited housing companies use pattern books or typologies for their house types, yet they are plagued with poor performance quality. Thus, how can typologies be developed that can be used for plans, design details, manufacturing details, and erection details that can be repeated and enhanced after each use, specifically focused on the housing association sector and also the small and medium enterprise developer, such as LiveEco; that achieve superior acoustic, fire, and thermal performance. Will all engineered timber systems be effective i.e. cross laminated timber, which is structurally supporting and can be used for walls, floors, and ceiling and roof panels, or closed panel systems such as structurally insulated SIPs. How will it be manufactured, which tree species can be used and how will the design details be translated into the manufacturing details. Plus, which Welsh OSM can manufacture breathable walls.
Academic 3	One of the most significant post occupancy problems with using timber facades is that it is well documented that thermal comfort far exceeds healthy temperatures. Littlewood has monitored timber frame apartment buildings that exceed 40 degrees Celsius with exterior temperatures of just 20C (Nooraei et al, 2013). Therefore, during the design and modelling of thermal performance how can thermal be designed into the structure to prevent overheating and how can natural materials be used for this function.
Technical 4	What is the most appropriate engineered timber system using home grown timber that allows breathable exterior facades and roofs, and therefore does not need plastic membranes? Will a home grown approach be durable enough against the west weather in Wales, prevalent in other west coast locations in the UK? Thus, how can the manufacturing process be enhanced in order to use home grown timber, this could be use of different types of jointing detail, but could also be related to introducing more ecological materials such as breathable facades without plastics, but instead using natural materials such as wood-fibre board.
Academic 4	After the disastrous Grenfell fire in London, how can building performance assessment techniques developed by the SuRBe group, such as in-
	manufacturing testing and also in-construction testing be used to ensure that no defects occur in the manufacturing and erection processes and result in air gaps in timber systems that can provide passage of smoke, fire and toxic gas. In addition, to contributing inadequate acoustic performance and also thermal.

The housing case studies for this project will be drawn from some of the housing developers in the Home-Grown Homes (HGH) Rural Development Programme, developed by Woodknowledge Wales (2018b) for Powys County Council. The £1.5 million HGH project commenced in April 2018 for 33 months, to spearhead the development of seven housing schemes across Wales using UK timber and eventually from Wales (Woodknowledge Wales, 2018[c]). As such the work plan for the project is as follows in Table 2 below.

Table Two: Doctorate work plan

Work Package No.	Work Package Title	Dates
WP1	Literature review – Timber Construction Supply Chain Assessment	06/18-12/20
WP2	Engagement with Timber Construction Supply Chain & Best Practice Timber Construction Assessment	07/18–01/19
WP3	Analysis and Production of Phase 1 Typologies	10/18-05/19
WP4	Building Performance Testing, Monitoring & Occupant Engagement	04/19-03/20
WP5	Analysis and Refinement to Typologies	04/20-08/20

WP6	Dissemination & Training with Wood Knowledge Wales	09/20-11/20
WP7	Thesis and Examination	12/20-05/21

DISCUSSION

This project will help further demonstrate the value and relevance of Woodknowledge Wales to the forest industries, construction, private developer, and housing association sector, and also the Welsh Government. This will help us attract new members from each of these sectors – our first income stream, help attract delegates to our events – our second income stream and lead to a new income stream and that is an advisory role. In the advisory role this will be to advise on the use of the typologies by OSM manufacturers, designers considering using them, and developers. In addition, our advisory role will extend to the forest owners in Wales as to the most appropriate timber to grow in the use of the typologies. Finally, our advisory role will also be on how to monitor the effectiveness in the use of the typologies during manufacture, erection, and occupation with the various building performance evaluation strategies adopted.

The outputs of the project will include a set of typologies for construction details, manufacturing details and erection details to achieve acoustic, fire and thermal performance, yet allow durability of finishes for low cost maintenance using a range of engineering systems using home grown timber; leading to enhanced occupant thermal comfort and therefore health and wellbeing. There will be two typologies, one for RSLs that have adhered to the Welsh Governments development quality requirements (WG, 2005) and also one set for SME developers, which exceed Welsh Buildings Regulations and transitions booth these sectors to zero carbon homes.

The project fits well with WG priorities since the lessons learnt from the project improve the innovation housing programmes legacy in that main of these schemed do not move forward housing quality after the extra funding has been exhausted. Typologies for the design, manufacturing and erection process with a POE evaluation process that can be repeatedly used by RSL and SME developers and enhanced will ensure that housing quality and innovation for home grown timber continues to grow in Wales.

This project meets the Welsh Government's Wellbeing of Future Generations Act (2015) in relation to Resilient Wales, Prosperous Wales, a Healthier Wales, a More Equal Wales, and Cohesive Communities in Wales and a thriving Culture in Wales.
A prosperous Wales because by encouraging the adoption of Home Grown timber using innovative engineered timber and OSM techniques where timber is a natural and renewable resource this ensures that timber is used efficiently where waste is limited or eradicated. This will lead to increased interest and specification of these materials. Thus, through demand and supply more trees will be planted and this is a carbon sink and helps lessen climate change. In addition, this increases the need for jobs in rural location and therefore retains and greatest wealth in these areas of Wales. A Resilient Wales, because timber regenerates, and through

proper management and planting enhances biodiversity in the undergrowth, and thus help eco systems flourish.
A Healthier Wales, because by increasing the number of timber dwellings from home-grown timber that include breathable walls this improves indoor air quality, and following the detailed modelling and monitoring the typologies will provide innovative solutions for homes that provided comfortable internal environmental conditions. There is emerging evidence well-conceived and delivered timber construction (in homes, schools and hospitals) is having positive health impacts. This is due to some or all of the following: good Indoor air quality (wood helps regulate internal humidity levels reducing condensation and reducing airborne pathogens and has low or zero emissions of harmful volatile organic compounds), positive psychological impact (Increasing evidence of biophilia, which is an innate and genetically determined affinity of human beings with the natural world).
Added to the above health benefits to occupants, the timber industry helps to sustain a healthy natural environment. By way of contrast, the above claim cannot be made for the UPVC Window industry or the Polyurethane Insulation industry to give but two examples.
A more equal Wales because low energy timber housing will help to reduce fuel poverty. Furthermore, the timber industry is very diffuse and involves mostly small companies. Unlike large centralised industries (e.g. steel and concrete) the timber industry is largely run by regionally rooted businesses. Cohesive Communities as using local materials and regionally rooted businesses to construct housing can help to foster community development and cohesion (particularly in rural areas) whilst at the same time, delivering a better end product. This can be illustrated by contrasting the output from volume house builders and speculative developers with that of local authorities, RSLs, and selfbuilders.

Finally, a Thriving Culture in Wales because Wales has entrepreneurial, adaptable, and localised cultures. Woodlands, timber and buildings are steeped in our history. The development of a new Vernacular architecture, an architectural style that is designed based on local needs, availability of construction materials and reflecting local traditions and labour would reenergise our communities and native culture.

CONCLUSION

This paper has introduced a Knowledge Economy Skills Scholarship 2 doctoral project that is developing and testing the performance of typologies for exterior fabric details used in the construction or offsite manufacture of highly innovative, and healthy homes using home grown timber from the UK, and where possible from Wales. The context to the project has been discussed as has the methodology with seven phases and the relationship with the Home Grown Homes project.

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THE ADOPTION OF A DESIGN BUILD APPROACH IN RETROFIT PROJECTS – A DESCRIPTIVE CASE STUDY

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Keywords: *Collaboration, design build, restoration, case study*

Abstract

The delivery Design Build projects across the built environment in Ireland has begun to take significant shape. There are many examples of the traditional are moving towards more collaborative practices. There exists support for the integration of a design build project approach in the retrofit realm where designer, client and developer can work collaboratively. As with the regular design build process the intent behind this collaborative approach is to encourage those associated with the built environment to consider how retrofit design and construction can contribute positively to addressing elements of climate change and the design build process. The opportunity to share the rich nature of the design build process in a unique environmentally and heritage focused project excited the authors. Secondly concerns about the way such projects are captured historically, and specifically the disciplinary knowledge and skills employed in the restoration of such a significant landmark building could be lost if not afforded some place in the research annals. This paper presents a Restoration Design-Build (RDB) process employed in the realignment of a state building in the United States adopting this novel initiative. The author, working closely with the design build manager, adopted a descriptive case study method to enhance the capabilities of understanding and generate constructive reflections and analysis. The intention was to empower the reader to explore new horizons by 'clarifying and negotiating' ideas and concerns around the RDB process. The author evaluated the usefulness of the RDB approach based on direct and indirect measures. The framework approach presented is a part of an ongoing initiative between state and project stakeholders that have shown positive results based on the teams' performance in the presented case study as well as affirmative feedback from some stakeholder participants. The positive measures adopted in this project are shared with the view of trying to encourage those associated with restoration project to adopt this approach.

INTRODUCTION

The AEC sector is quite often criticised as an industry that consumes 40% of global energy consumption and waste generation, and 25% of the global water consumption (Balasubramanian and Shukla, 2017). This had created a global interest towards delivering green buildings, which in turn has brought attention to the Retrofit sector in the AEC. Preserving the past is now considered as an important factor for societies cultural and natural heritage, which it is argued must evolve in order to survive. Working with other disciplines and engaging stakeholders, historic preservation specialists manage change in the physical environment. Recognizing the dynamic and multifaceted nature of the field of historic preservation will help

prepare the next generation of change agents. This mission is met through forward thinking, multidisciplinary teamwork, hands-on learning opportunities, and partnerships with experts, public agencies, and private organizations across the US and globally. New construction is not always the answer to a clients' building needs. Often, the renovation of commercial and residential property can just as effectively provide expanded space and fresh architecture. Society needs to recognize the value of an existing structure, especially if the location of the property is desirable. In many cases, clients may simply need to update their properties in order to meet building codes and comply with insurance standards. However, some clients have the vision to set about preserving the past and make that contribution to humanity.

What sets restoration apart from other construction projects is the fact that the project team are taking an already designed, engineered and constructed, often historic, building to a new place where it takes time to do the work properly. Being very sensitive and conscious to maintain the integrity of historic homes (often stately) and buildings in order to preserve them is the key to the success of this type of work. The setting of high standards to ensure that the protection of the original materials and features, like masonry units (brick, limestone, granite, terracotta, etc.), is the important focus, particularly as decay can be a consideration. There are specialist agents who are proud of high rates of being able to salvage even the most worn masonry units to ensure preservation of the original building material.

Trends in the Delivery of U.S. AEC Projects

In the US, the infrastructure sector has experienced a number of changes in preferred project delivery approach over the last century or so. Until the end of the nineteenth century, concurrent delivery of design, construction, and long-term operations was mandated and facilitated largely by state statutes. In particular, the fact that design professionals were not organized in strong professional organizations allowed for an environment in which designers were subordinates to constructors and not collaborators (Pietroforte and Miller 2002). These factors, including others, have led to a wide application of integrated delivery methods. By the end of the Century, however, certain historical developments produced a push to segregate design and construction activities. First, design-oriented professionals organized themselves into professional societies, such as the American Institute of Architects (AIA) and the American Society of Civil Engineers (ASCE). The interests of these groups was supported by growing public concern over the quality of construction-directed design activities. As a result, segmenting the procurement of design and construction services was first allowed by the U.S. Congress in 1893; however, the infrastructure sector's use of this split delivery method was not fully assumed until passage of the Federal Aid Road Act in 1916 (Pietroforte and Miller 2002; Rein et al. 2004). Following 10 years of development, the preparation and launch of Public Buildings Act, the federal government required for the first time that design and construction services be procured separately, a landmark occasion.

Subsequently, the Great Depression "eclipsed the private funding of public projects and the use of the combined project delivery methods" (Pietroforte and Miller 2002; pp.428). So from that the government preference for using segmented approaches to delivering projects increased through World War II. This shift was later reaffirmed in both the 1956 Federal Aid Highway Act (Rein et al. 2004) and in 1972 the Brook Act, each furthering the separation of design and construction procurement activities (Pietroforte and Miller 2002). Thus, the result of this

sequence of events, governmental agencies developed their project delivery strategies around the low-bid procurement approach of a single delivery method, the Design-Bid-Build (DBB) method as we know it today. In the transportation sector most particularly, after decades of continuous use, this method became the institutionalized standard for the delivery of projects.

The infrastructure sector is currently reencountering the issues surrounding delivery strategy change; the sector-wide standard for delivering projects, the DBB method, is experiencing a deinstitutionalization. According to Oliver (1992), "deinstitutionalization refers to the de-legitimation of an established organizational practice [...] as a result of organizational challenges to or the failure of organizations to reproduce previously legitimated or taken-for-granted organizational actions" (pp.564). In response to both an increasing demand for new capacity and for minimizing the impact of construction to motorists, the transportation sector is questioning the ability of a project delivery strategy that is based solely on one delivery method; several studies have shown the poor performance of this method in terms of schedule (i.e., overall duration and schedule certainty) when compared with other methods (FHWA 2006; Ibbs et al. 2003; Sanvido and Konchar 1997). Over recent years, these concerns have generated a reduction of legal, regulatory, and practical impediments to integrated delivery methods for delivering new infrastructure projects across all sectors of the AEC (Kennedy et al. 2006; Papernik and Davis 2006), including smaller type design build projects (Nyström et. al. ,2017 and Minchin et. al., 2013).

Potential Problems Associated with Changing Project Delivery Strategy

As the decades-long use of the segmented DBB method has so fundamentally shaped employee perceptions and organizational structures and practices, implementing a combined procurement approach constitutes a paradigm shift for the state agencies adopting it (Miller et al. 2000). Studies have identified that "as agencies attempt design-build for the first time, they are constrained by the low-bid culture in their organizations" (Molenaar and Gransberg 2001). In the report to Congress on Public Private Partnerships (PPP), the U.S. Department of Transportation acknowledged these difficulties, reporting that "states not accustomed to this method of procurement can find it difficult to oversee these types of projects" (FHWA 2004). In addition, although combined procurement of services is expected to reduce transactional costs for delivering a project (Pietroforte and Miller 2002), this new type of procurement usually results in state personnel spending considerable time experimenting and developing new organizational routines to support the procurement change (FHWA 2004). These time excesses are often justified by a wider concern that traditional safeguards embedded in traditional procurement and financing approaches can be lost in the change process (FHWA 2004). So is there a need to have a more collaborative approach for restoration project delivery? Some might say no, it is the view of the author that projects like the one described in this paper can only support that adoption of an a more collaborative approach.

Ghosh and Robson (2014) offered that in order to complete the Empire State Building under the allotted 18 month schedule the contractors employed innovative construction methods and techniques. They argue that many of the construction methods qualify as tools of lean construction practiced in today's construction industry. Their paper, 'Analyzing the Empire State Building Project from the Perspective of Lean Project Delivery System' (2014) examined the design and construction processes of the Empire State Building and compared them with

the Lean Project Delivery System (LPDS) processes that are increasingly employed in the construction industry today. Many contractors in the restoration have begun to consider such approaches.

Therefore, especially in the restoration area, an effective implementation of this paradigm shift requires owners to correctly identify the dimensions of change in the delivery cycle in order to establish new work relationships with contractors, suppliers, and consultants. These challenges to changing a project's delivery strategy are summarized below in the problem statement of this research effort. Since the adoption of, what might be referred to a Design Build in Restoration approach is a response to changes in the AEC environment, owner organizations are compelled to seek ways to adapt their organization to the new approach. This adaptation requires the development of new work processes along the delivery cycle, and involves the implementation of these processes within new organizational structures. This research effort will share some of the lessons learnt from the process captured from the implementation of a novel restoration design build (RDB) project.

Solving a Distinct Historical Restoration imperative

The rationale behind this research is two-fold. The first motivation arose from reflection on the type of project delivery strategy communicated by the state of Oklahoma for the restoration of the State capital. The opportunity to share the rich nature of the design build process in a unique environmentally and heritage focused project excited the authors. Secondly concerns about the way such projects are captured historically, and specifically the disciplinary knowledge and skills employed in the restoration of such a significant landmark building could be lost if not afforded some place in the research annals.

It is the coincidence of the changing design build focus in restoration projects, and complex disciplinary challenges that coalesce to provide the rationale for this research.

Descriptive Case Study approach

The use of case study research within built environment research and development initiatives explicitly recognizes that an attempted to explore the field of study, as defined in the title, and gather information on it is the basis for an appropriate. In order to do this exploration, data was collected and assimilated from formal and informal observation, field notes, vignettes and reference to (researcher-written) profiles and reports, and individualized educational programs. Case study designs and applications can vary widely: They may be used for either exploratory, descriptive or explanatory purposes, and may take either typical, critical or deviant approaches. To further compound the situation, they may be prepared by a wide variety of processes and so cause complexity.

Descriptive case studies may be exploratory, if relatively little research has been done in the area, or they may be illustrative of aspects thought to be representative or typical: Both exploratory and illustrative aspects may be included in a single case study, with accent being on the typical. Hakim (1987) has classified descriptive case studies as typical, or selective: The typical, we have already introduced above. The selective case study may focus on a particular issue or aspect of behavior with the objective of refining knowledge in a particular area, to provide a better understanding of causal processes. The selective case study may lead to

questions about 'how' and 'why' issues or behavior conspired to produce the resulting outcomes: This leads into explanatory evaluation.

Case studies may either focus on a single case or use a number of cases: A single case may form the basis of research on typical, critical or deviant cases, while multiple cases may be used to achieve replication of a single type of incident in different settings, or to compare and contrast different cases. Multiple-subject case studies are especially useful if topics are too complex or involve too many actors to be addressed using a simple interview survey. Single case studies are analogous to single experiments, and as such are justified using the same arguments as the single experiment. This single case study provides the context for capturing a historically significant building's redevelopment and offering a reflective paper to share those elements that may contribute to a better understanding for future built environment professionals to advance with some level of clarity and direction.

The Design Build Process

Project Delivery is a comprehensive process in today's AEC sector and includes planning, design and construction along with the post construction requirements to complete a building facility or project. Adopting the most appropriate delivery method is one of the fundamental decisions owners make while developing the acquisition strategy. In the traditional design-build project delivery method, the DB is responsible for both the design and construction stages of the project. Table 1 identifies different Project Delivery Systems, Procurement Methods and Contract Format for different types of Construction Projects in the Built Environment.

Table 1: Project Delivery Systems, Procurement Methods and Contract Format for Construction Project.

Project Delivery Systems	Procurement Methods	Contract Format
Construction Management at Risk (CMR) also known as CM/GC Design-Bid-Build (DBB) Design-Build (DB) Multi-Prime (MP)	Best Value (BVS) Low Bid Negotiated Qualifications-Based (QBS) Sole Source (or Direct Select)	Cost Plus Fee Guaranteed Maximum Price (GMP) Lump Sum (or Fixed Price) Target Price Unit Price

Through well-developed relationships with trade partners, Restoration Design-Build (RDB) can provide a cohesive team for every step of the project process. By utilizing this team approach throughout the design and construction phases, like Design Build, the restoration DB approach is able to minimize project risk, control project cost, and reduce the delivery schedule. The design-build process allows the project to be owner driven as the construction program

maximizes the owner's value at the completion of the project. There is one firm, one contract, one integrated flow of work from design inception to project completion.

Overview of RDB Process:

Design Process:

- Initial Consultation
- Preliminary Design and Project Cost Range
- Design Partnership Agreement
- Development of Existing Conditions and Project Design Alternatives
- Design Revisions and Materials Selection
- Final Design Approval
- Construction Contract

Build Process:

- Scheduling and Materials Ordering
- Project Initiation – including health and safety protocols
- Ongoing Construction planning and updates
- Project Completion
- Completed Project Consultation (important phase of the project)

The advantages associated with the RDB process include:

Reduced Financial Risk:

- Eliminates the risk of paying for complete drawings that do not fit within your budget once construction costs are determined.
- The project is designed to fit within the client investment comfort range
- Problem solving is completed during the design phase, not during construction when they can become more costly.

Efficiency:

- Allows for a shorter, smoother construction process.

Accountability:

- Design-Build maintains complete accountability of your project at all times.

Background of the Project and the Stakeholders

"The State Capitol Building represents who we are as a people. It resonates with the spirit of the people who have walked through its hallways or sat in its chambers for the past 100 years. The State Capitol of Oklahoma is a functioning historic and irreplaceable treasure, serving the people of our great state, as a building, a museum, and a repository of our government's past, while simultaneously, the constantly evolving headquarters of its future, in both its daily use and governmental guidance" (Oklahoma Capitol Restoration CAP Solicitation No. 15151DB Report, 2014).

It took three years and $1.5 million to build Oklahoma's Capitol building a century ago. It will take at least six years and as much as $245 million to prepare the building for its next 100 years. Plans and design work to repair and renovate the 452,000-square-foot building were completed based on the historic data archived.

The work schedule identified that the building's exterior restoration would begin in July 2016 and the interior in September of that year. Trait Thompson, the Capitol project manager for the Oklahoma Office of Management and Enterprise Services, reported that the project would involve every square inch of the capitol building. Details of the project include:

COST: Estimated at $245 million; $120 million in bonds authorized by Oklahoma Legislature and another $125 million bond issue pending.

DURATION: Exterior work to take an estimated 3.5 years; while the interior work to take an estimated six years.

EXTERIOR REPAIRS:

- Eleven levels of scaffolding to be erected.
- Repair 21 miles of mortar joints.
- Repair 240 cracked or damaged stones.
- Restore 477 windows.
- Restore 43,000 pounds of cast iron.
- Expand exterior loading dock
- Replace exterior doors
- Partial roof replacement
- Repair exterior stairs, plazas, sidewalks and battlements.
- Repair east tunnel.

Reflections on the use of Design Build Process in Restoration

Existing buildings and legacy project systems can offer distinctive challenges which are technical (e.g. access to archived data, capturing & maintaining accurate as-built data, lack of interoperability, high data volumes), organizational (e.g. public representation, stakeholder collaboration, new workflows) and cultural (e.g. learning curve, learning on the job, increased effort) in nature (Volk, Stengel, & Schultmann, 2014). In some cases, sections of the restoration facility may remain operational during upgrades, adding another particular layer of operational complexity. Despite these challenges, the construction trades face increasing pressure to; (a) maintain a high level of performance to ensure a faster time to market for the manufactured products and (b) optimize construction labor headcount to alleviate the congestion on site.

Some of the fundamental points that provide a depth of learning for all stakeholders include:

- Allow the members of the team to share their knowledge and gain confidence - allow and schedule time for this as this will require more time than you might expect
- Encourage them to schedule meetings outside of the designated time
- Encourage the team members to challenge assumptions
- Ensure that project team members, especially those who will have to travel to meetings acquire as much background knowledge as possible
- Embrace stakeholder -led collaborative efforts that lead to team success and look for ways to foster it
- Make any expectations clear to all project team members.

This kind of truly collaborative approach demands a major time commitment and agreed/ shared goals. One cannot assume that the team members know what it is they are going to say and roll with it as easily. Be prepared to have situations that will take more time than you might have scheduled for, especially as time will be gained in the execution of work when clarity around objectives is achieved. The time spent will allowed team members to deepen their understanding of the requirements to be successful, improve interactions with each other, develop a capacity to embrace differences, and work toward a more collaborative approach to solving the project.

Discussion and Future Direction

The authors reflected on a number of advantages in the collaborative RBD project - social benefits, learning benefits, and development of skills, knowledge and competences of the participants for their future careers. The early stage meetings be embedded to reduce the social anxiety of students by providing an instant group of peers with whom they would not feel exposed. Instead they would feel a sense of community through engaging in the common task of grappling with and understanding the competition structure and the material associated with it. Secondly, it was hoped that the method would help to promote deeper understanding, especially for the international audiences as their knowledge and experience in the US construction processes is very limited.

Due to the historic nature of the building, those associated with the project often do not know what they are getting into until the disassembling of components has commenced. More specifically, the windows on the Oklahoma Capitol project are specific to this building and through a focused and collaborative investigative process, the design-build delivery method really assists in coming up with resolutions quickly and with little cost. The opportunity to collaborate and discuss matters as they emerge as a shared ownership of the project is clearly observed. On the contrary, if this were a traditional delivery method, for any unforeseen conditions or changes that need to be made, the team would have to follow the traditional protocol of notifying the Owner, contacting the Architect, receiving a stamped set of drawings to denote the changes made, etc. In Design Build, the project team very simply make a decision and implement it immediately – documenting everything in an as-built manner.

One of the primary benefits of design-build is also the shifting of risk from one primary group (i.e. the architect or contractor) to the entire group. This is especially beneficial for this historical project owner, with the large amount of risk that could be involved with restoring a 100-year-old building. When the team run into issues on-site, the design-build team understands that whatever decision is made, everyone on the team shares the same risk if that decision turns out to be incorrect or flawed. This delivery method truly forces everyone on the team to work together for one common goal: to complete a successful project.

The understanding of the complexity of the advanced technology repair methods employed was a major limitation for this study as the expert masons hired for the project were from Poland and communication proved difficult. Also, frequent changes give the construction trades limited time to react, thus lowering their productivity. The retrofit conditions also affected productivity, for example as health and safety was a huge concern on this public facility which remained in use during the restoration period impacted on how the project progressed. The lack of an existing formal method for measuring productivity for the project made it difficult to compare our observations against a baseline, such is the nature of restoration work. The second limitation is in the research method. Nevertheless, despite the limitations of a case study method, the complexity of the construction environment and the integration of the researchers in the field provides a solid foundation for analysis and conclusions. As Glaser & Strauss (1967) argue; it is the intimate connection with empirical reality which permits the development of a testable, relevant and valid theory.

Changing from a low-bid, design-bid-build process to a best value, competitive Design Build process for delivery of a facility is not easy. Information about how this change should be implemented is limited, especially at the organization-wide level.

The significance of using well qualified personnel on a project of this nature is that if contracted correctly from the beginning of the projects lifecycle, offers opportunity for the development of high performing facilities through sustainable building construction processes with fewer resources and lower risk than a traditional process. It can be argued that, within the framework of alternative project delivery methods, project management strategies and collaborative work environments, will affect improvements in the construction supply chain. The first objective of this paper was to present a background to the implementation for a retrofit project. It was found that there is limited published research on RBM use for construction projects, with most publications offering research related to sharing project accomplishments. However, there are limited studies which have qualitatively and quantitatively examined the impact of retrofit and

its contribution to dealing with old buildings allows us to consider each part of the structure as an individual element that makes up the whole. Such analysis is of concern and should be especially so to owners. To this effect, as part of future research, a RDB framework be developed and proposed which will evaluate the stakeholder expectations driving the decision-making during the planning, implementation and use of appropriate conservation methods and their impact on task-level labor performance. The AEC sector in general can benefit by extending a RDB framework as a methodology for future projects.

CONCLUSION

The purpose of this paper was to articulate the reasons behind AEC industry change in perspective and altitude. The drivers for adopting collaborative and green strategies in construction have been acting as a catalyst to change in the dynamics of AEC industry. This has resulted in the increased development and proposed applications of BIM based sustainability models. The relevance of the increasing recognition of the synergy benefits is clearly supported by the evolution of different themes in restoration projects that are trying to deal with the many complexities involved in this specialist type of project. The findings of this paper provided insight into the areas that need development to reach a consistent and mature level of integration between the type of approach in restoration but also the nature of stakeholder involvement. Essentially, it has been argued that more development is required in capturing the practice struggles with the alignment of the RDB process.

Other findings from the research for the paper is the gap that has been found in academic literature in providing solutions and framework for the synergy developed from the approach to restoration design build by the sector with dealing and the charting of best practice. Further work is required to analyse real-life project problems where the results can contribute sufficiently to offering a framework for RDB.

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CSR/Policy

IMPLEMENTATION OF CORPORATE SOCIAL RESPONSIBILITY IN SOUTH AFRICAN CONSTRUCTION SMALL AND MEDIUM ENTERPRISES

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Abstract

Theories on Corporate Social Responsibility have traditionally focused on larger companies, due to their global presence and income generating ability. Research concerning CSR in SMEs is scarce, yet SMEs constitute a significant component of national economies and industries worldwide. The misconception that CSR initiatives are expensive to implement, along with the fact that many SMEs are not aware of what CSR entails, serves as the motivation for this study. A total of 37 randomly selected construction contractors, taken after a sampling frame was applied, participated in the study. Quantitative data from 37 South African small to medium sized construction companies were collected using a structured questionnaire. CSR implementation levels were divided into three components, namely, environmental, social and ethical. Each of the three components was further broken down, and implementation scores were aggregated and analysed. The primary objectives of the study were to examine firstly the awareness level of SME's and secondly their concern about the cost of CSR. The results suggested that SMEs operating in the South African construction industry have implemented a handful of CSR initiatives. Most the SME's that completed the questionnaire were found to exercise both the environmental and economic aspect of CSR; yet implementation concerning social initiatives was limited. Non-parametric correlation analyses showed that higher awareness levels of CSR led to higher levels of implementation. It was also found that the concern about the cost of CSR negatively affected implementation levels, yet SME's still incorporated a few CSR initiatives into their business operations. A less than ideal response rate of 11% presented the major limitation of the study. The study comprised of general building works contractors only. Future studies concerning CSR in construction SME's could include other industry participants such as architects or quantity surveyors. The inclusion of these could provide a more holistic representation of the South African construction industry.

INTRODUCTION

Corporate Social Responsibility (CSR) represents an ongoing commitment by a company to operate in both a responsible and an ethical manner while contributing to sustainable and economic development. Chiveralls, Zuo, Zillante, Wilson and Pullen (2012) believe CSR aims to decrease the harmful impact of business operations while simultaneously maximising the benefits that arise from positively affecting society and the environment at large through good corporate governance. Bevan and Yung (2015) state that construction companies have come under substantially increased pressure from national governments as well as environmental

organisations to operate more efficiently and sustainably. This is primarily attributed to the rise in societal awareness of the need for sustainable development across the entirety of economic development (Schmidheiny, 1992). Apart from the fact that the construction industry provides the physical infrastructure that national economies require to expand, it provides millions of people with employment and is the ideal means for socioeconomic upliftment (South Africa, 2003; Teo & Loosemore, 2003). The call for greater CSR integration in the construction industry is justified by its alarming rate of natural resource consumption, combative industry participants and the permanent nature of its finished goods (Teo & Loosemore, 2003; Martinuzzi, Kudlak, Faber & Wiman, 2011).

Traditionally CSR has primarily focused on large companies and their operations (Sweeney, 2007). The rapid expansion of large companies, coupled with their global impact, has rightly warranted calls for increased transparency. SMEs, however, remain in the background; this is partly due to their size, as well as the public's lack of knowledge about SME operations. Apart from the fact that SME's are entirely different to their larger counterparts, on both a management level and an operational level, CSR concepts and frameworks have traditionally focused on larger companies. This even though SME's account for 63% of employment in the South African Construction Industry and 43% of the income generated (Jenkins, 2006; Porter & Kramer, 2006; Stats SA, 2014).

A possible reason for the lack of CSR participation by SME's could be the lack of a universally clear definition (Chiveralls *et al.*, 2012). Along with the uncertainty about what CSR entails, studies conducted in Australia and England suggest that SMEs do not often refer to their businesses as practising CSR, yet their activities fall under the broad spectrum of CSR. Another possible reason for their reluctant involvement in CSR initiatives is the misconception that CSR is costly to implement regarding both time and financial resources (Kechiche & Soparnot, 2012).

This paper seeks to fulfil two primary objectives: firstly to identify the relationship between awareness and CSR implementation levels by SMEs operating in the South African construction industry, and secondly, to measure the relationship between SME's economic concern and their level of CSR implementation. The findings of the study will provide SMEs in the construction industry with valuable knowledge about CSR, therefore assisting them in creating their unique CSR strategies proactively.

LITERATURE REVIEW

Evolution of corporate social responsibility

The concept of CSR has both a rich and varied history (Carrol, 1991:268). Early writings on CSR are often regarded as a business responsibility because the age of corporate empires and conglomerates was not yet entirely prevalent in the business sector. The foundation of CSR is laid by Bowen (1953) in his revolutionary book entitled "Social Responsibilities of the Businessman". This book is argued to be the birth of all future literature on the topic (Carrol, 1991:269). The underlying reason for the book's publication is Bowen's belief that large companies are crucial centres of power and directly affect the surrounding communities (Bowen, 2013:29).

Since this ground-breaking book was first published, there has been a gradual transformation in the terminology associated with the responsibilities of a business to the now widely known CSR. The field of knowledge concerning CSR has grown exponentially and today encompasses many theories, definitions, concepts and policies (Garriga & Melé,, 2004:51).

A global paradigm shift towards sustainability has affected every known industry (Schmidheiny, 1992). According to Kuckertz and Wagner (2010:526), this paradigm shift towards more sustainable economic behaviour has led to the development of solutions for today's environmental and social dilemmas.

Hubbord (2009:180) believes the emergence of sustainability concepts has forced many companies to re-evaluate the way in which they approach the measurement of company performance. One such performance-measuring tool is the Balanced Scorecard (BSC) measurement system introduced by Kaplan and Norton (1992). The introduction of this tool has gained popularity in many large organisations. At the time that companies started to adopt BSC, media and community groups simultaneously began to pay more attention to the effect company operations were having on both the natural environment and society. In most countries around the world, there was landslide consensus regarding broadening companies' responsibilities to extend further than just creating economic value. This shift in public perception led to the birth of the Triple Bottom Line (TBL) concept by Elkington, (1997) and used a new tool to measure company performance holistically.

Corporate social responsibility in construction

Construction is a major industry in all economies of the world. The industry is responsible for a sizeable portion of most countries' Gross Domestic Product, along with Gross National Product. The significance of the CI goes further than its size, and embraces its role in stimulating economic growth (Dlamini, 2012:1). The United Nations Centre for Human Settlements (HABITAT, 1996:142), agrees with this notion but also adds that the construction industry plays an integral role in the development of socio-economic solutions in countries. The industry is responsible for providing buildings and infrastructure, and allow such developments to occur. Apart from its direct contribution to growth, the industry also provides millions of employment opportunities.

It has been well documented that CSR in the construction industry has gained considerable attention over the years, due to the impact the industry has on National GDP, the environment and society itself (Murray & Dainty, 2009:9).

Jenkins (2006:241) believes there is a rising demand by the wider public for companies associated with the construction industry to provide information that is more detailed and also to show greater accountability regarding their business operations, which affect both society and the environment. This pressure has resulted in businesses publicly showing their participation and commitment to CSR endeavours.

It is the impact of the construction industry's products on communities that presents the core reasons for raising the profile of CSR in the industry. Construction projects, along with the individuals that influence them, such as architects, engineers, etc., provide an opportunity for businesses to create a profit as well as to leave a lasting socio-economic legacy that can help to

shape future generations. Obviously not all construction projects are welcomed with open arms. Distinguishing between projects which are truly beneficial to the community and those which are simply smokescreens for corruption, is required to prevent the use of misappropriated taxpayer's money in the case of public projects (Murray & Dainty, 2009:9).

Corporate social responsibility in construction small and medium enterprises

Traditionally CSR has been primarily focused on large companies, therefore is a considerable lack of knowledge concerning SMEs (Sweeney, 2007). Multiple assumptions have been made regarding CSR in SMEs. Once such assumption is that SMEs are viewed as "Little big companies" (Tilley, 2000) and initiating the advance of CSR can easily be downscaled to fit the SME.

Westhead and Storey (1996:18) state that theoretical concepts regarding SMEs must consider factors such as the motivations, limitations and the uncertainties SMEs encounter. These theories must recognise that obstacles faced by SMEs differ considerably to those of larger companies.

The rapid expansion of large companies, coupled with their global impact, has rightly warranted calls for increased transparency. SMEs however remain near invisible and are unlikely to view CSR in terms of risk to their company's brand image or notoriety (Jenkins, 2006). In the case of SMEs, relevant issues are far more likely to spark interest, for example, employee motivation and retention, and community interaction. Baker (2003) believes that as many as 60% of SMEs are primarily concerned with survival, so provided they are in business, there is little need to incorporate CSR into operations. Other research has suggested that SMEs are in a more advantageous position to benefit from CSR initiatives due to their close relationship with surrounding communities (Sarbutts, 2013).

In a study carried out by Branco and Rodrigues (2008:686) on the factors influencing CSR in companies, they propose that companies engage in CSR initiatives due to two distinctively different motivations, namely internal company procedures and external stakeholder and legislative requirements. Branco and Rodriguez (2008) believe some companies participate in CSR due to the belief that having positive relationships with their stakeholders is of benefit to the business, for example, increased financial returns realised by developing intangible assets such as human resources and capabilities. These assets could represent a competitive advantage and help companies differentiate themselves from their competitors. They believe many companies engage in CSR due to external pressures such as legislation and stakeholder demands, and these cause companies to make use of CSR initiatives as a legitimacy instrument to meet societal expectations (Branco & Rodriguez, 2008).

There are basic CSR fundamentals that all SMEs should be held accountable for, and amongst them are:

- The establishment of a comfortable work environment where diversity can flourish;
- An equal distribution of wealth throughout society, and
- Protection of the environment.

SMEs are often negatively portrayed in relation to such basic responsibilities (Bacon, Ackers, Storey, and Coates, 1996; Gibb, 2000).

Corporate social responsibility initiatives

CSR consists of four critical components, namely: environmental, social, ethical and economic CSR. It can be safely assumed that every company will endeavour to practice economic CSR or else it would cease to exist. Although implementation of economic policies may differ between companies, the differences are considered to be much smaller than those of the remaining three CSR components. The literature concerning SME's and CSR finds that many SMEs incorporate facets of CSR into their operations yet are not consciously aware of the fact that these activities fall under the CSR umbrella (Jenkins, 2006).

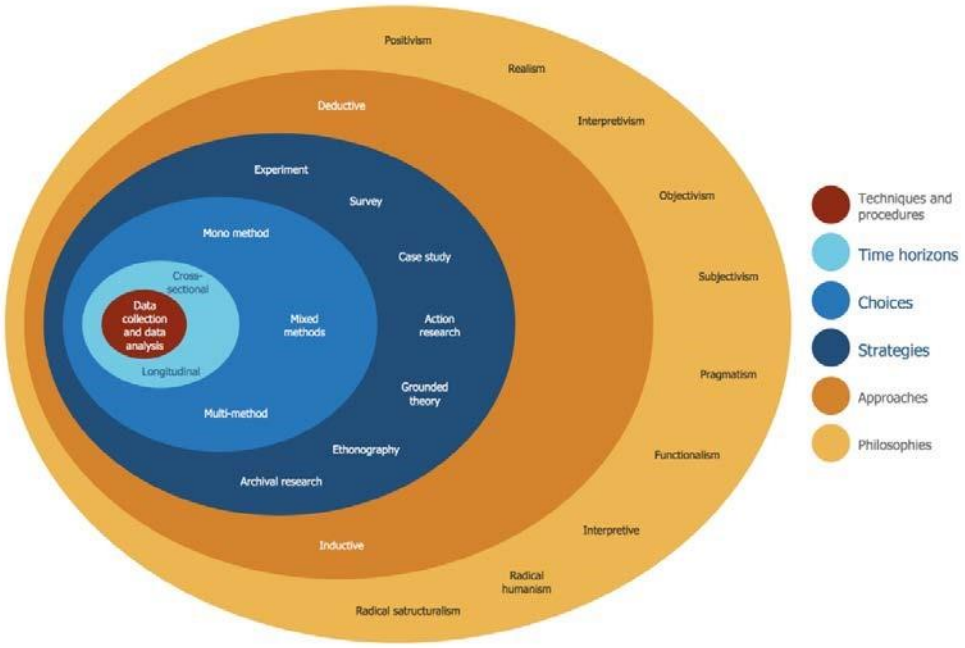
It is recognised that the (19) CSR activities used to test the respondent's' awareness levels cannot cover CSR in its entirety. Research suggests that implementation of CSR in SME's is affected by both the SME's ability to comprehend as well as its awareness of CSR. This theoretical assumption can be traced to studies and theories concerning the diffusion of innovations (Rogers, 2003). According to Rodger's diffusion paradigm, knowledge about a matter is the initial phase, which provides the catalyst for other phases such as persuasion, decision-making, incorporation and confirmation. This literature provides the background for the first objective.

The construction industry is notorious for its slow adoption of alternative procedures; this is evident in the case of CSR in the construction industry. Chiveralls *et al.* (2012) believe that the construction industry is primarily driven by compliance and seldom moves beyond minimum standards without a clear business incentive to do so. SME's lack the resources that their larger counterparts possess, therefore the misconception that CSR is expensive to incorporate often hinders the implementation levels of CSR in SME's (Horvat, 2015:345). However, no definitive link between CSR and costs has been established (Husted & Allen, 2007:594) The widely accepted economic principle, the law of demand, states that the higher the price of goods and services, the lower the demand, and this provides the theoretical background for the second objective.

METHODOLOGY

Research design

The research onion (Saunders, Lewis & Thornhill, 2015:124) is used to explain the research design for the study below.



A positivist philosophy was adopted in this research due to the following Ontological, Epistemological and Axiological assumptions:

- Ontology (nature of reality or being): The world was seen as external, and there is a single objective reality to any research phenomenon or situation regardless of the researcher's perspective or belief
- Epistemology (what constitutes acceptable knowledge): The focus was on discovering observable and measurable facts and regularities
- Axiology (role of values): The research was undertaken in a value-free way, the researcher was independent of the data and maintained an objective stance

A deductive research approach was used to explore the relationship between universally accepted theories and empirical observations. The deductive approach is an observational framework used to draw causal inferences guided by preconceived ideas.

A survey research strategy using a questionnaire was used that allowed for the collection of standardised data from a large population in a highly economical manner, allowing for easy statistical comparison.

A mono-method that amalgamates a single quantitative data collection technique with a single corresponding data analysis procedure was used. The mono-method research is used to critically evaluate one-dimensional causal effects and relationships between objects observed in reality.

A cross-sectional time horizon was used to provide a 'snapshot' taken at a particular time.

Population, sample size and sampling technique

The research population comprised of 2665 construction SMEs practising as general building works contractors; with CIDB grades 4, 5 and 6; operating within the South African construction industry. The population size with a 95% confidence level and a 5% margin of error translated to a sample size of 336 construction SMEs. Random stratified sampling was used in order to obtain SME representation from each South African province in the sample.

Questionnaire design

The objectives mentioned above entailed the measurement of three variables, namely the awareness level of CSR, the implementation level of CSR and the SME's concern about the economic aspect in the context of CSR. The primary data required for the research were collected through a structured questionnaire. The questionnaire was formulated based on a previous study on construction SME's in Australia by Bevan and Yung (2015), in conjunction with an extensive literature review.

In terms of the awareness variable, two measures were used, with one being subjective and the other being objective. In terms of subjective awareness, respondents were asked to select their level of understanding concerning CSR by selecting one of five possible outcomes ranging from "Very poor" to "Excellent". For objective awareness respondents were asked to identify from a list of 19 activities whether they believed these activities were related to CSR. The total percentage of correct answers constituted the measure of objective awareness. Both measures were then be tested for consistency by means of nonparametric correlation analysis. CSR is broad in context, therefore the 19 activities listed in the questionnaire could not possibly cover CSR in its entirety. The reason for the inclusion of an "Objective" variable is to assist in the testing of reliability of the subjective variable. If the two variables were found to have a positive correlation to any extent, the subjective awareness variable was deemed reliable.

As previously mentioned, CSR has four integral components, namely environmental CSR, ethical CSR, social CSR and economic CSR. Economic responsibility is practised by every business to the best of its ability, or else it would cease to exist. Regardless of whether the economic responsibility differs slightly between companies, the differences would be presumably smaller than those of the other three CSR components. Environmental, social and ethical CSR impact the wider stakeholders who have less direct impact on the company, therefore the literature in this study regarding CSR in SME's focuses primarily on these three components. Each of the three components was broken down into subsequent categories. This allowed literature to be identified that could provide insight into factors unique to each component that could affect both the type and the implementation of CSR in South African construction SME's.

The environmental aspect of CSR was broken down into ten questions, whereas social and ethical CSR were each broken down into eight questions. Each question could have a maximum score of 1 and a minimum score of 0. Two types of questions were used, with the answers being either dichotomous or on a five-point Likert scale. Questions requiring a dichotomous answer were used to identify the existence of a policy or initiative, whereas Likert scale answers were more suited to questions involving actual levels of implementation.

The answers to the Likert scale questions were scored according to the following rules:

- A level 1 scores a 0;
- A level 2 scores 0.25;
- A level 3 scores 0.5;
- A level 4 scores 0.75; and
- A level 5 scores 1.

The scores concerning the level of implementation for each CSR component were calculated using the formula (1.1) below (Bevan & Yung, 2015):

$$Level\ of\ Implementation = \frac{\sum_{i=1}^{n} Ai}{n} \qquad (1.1)$$

Ai denotes the ith component in the CSR; n denotes the number of questions in the CSR component (10 for environmental and 8 for both social and ethical), j represents the three aspects of CSR (environmental, social and ethical).

The calculation of the overall CSR implementation level was done using the formula (1.2) below (Bevan & Yung, 2015):

$$Total\ CSR\ Implementation = \sum_{j=1}^{3} \frac{Level\ of\ implementation}{3} \qquad (1.2)$$

The SME's concern regarding the economic aspect of CSR was measured using Spearman's rank order. Therefore, for this study economic responsibility was ranked No. 1, so if the respondent ranked economic responsibility 1, the score would be 1, if No. 2, the score would be 0.66, if No. 3, 0.33 and if chosen as No.4, the score would be 0.

Non-parametric correlation was used to determine the extent of the relationship between the participants' awareness level and level of CSR implementation, along with their concern for the economic aspect. If the SME's awareness level had a positive correlation with the implementation level, objective 1 was met, otherwise it was not met. If the level of concern for the economic aspect of CSR had a negative correlation with the implementation level, objective two was deemed to be confirmed, otherwise it was rejected.

Response rate

The questionnaires were administered by email. To ensure the questionnaire covered all the essential information, a pilot study on three SME's, was conducted in East London and Port Elizabeth. Thereafter 336 companies were contacted via electronic means, i.e. email or telephone calls, with 37 companies completing the questionnaire. The participation rate of 11%, although not impressive, is found to be acceptable because it was enough to generate accurate results with the correlation tests (Bonnet, 2000:24).

RESULTS

Demographics

Of the 37 construction SMEs responding to the questionnaire, most respondents came from the Eastern Cape and Gauteng (29.4% and 24.3%). Males accounted for 81.1% of the respondents. The age group of 45-54 accounted for 32.43% of the participants whilst 59.46% of the participants had work experience of more than 10 years, bearing testament to the fact that respondents held positions of authority in their respective companies.

Correlation between objective and subjective awareness levels of CSR

Table 1 reveals the subjective awareness levels of the respondents towards CSR. A total of 70% of the respondents (rating 1 [0%]; rating 2 [27%], and rating 3 [43%]) replied that they had very little knowledge of CSR. The remaining 30% felt they had either good knowledge (rating 4; 22%) or great knowledge of CSR (rating 5; 8%).

Table 1. Distribution of subjective awareness level

Knowledge level of CSR (n=37)	% of Respondents
1 = very poor knowledge	0%
2 = poor knowledge	27%
3 = moderately knowledgeable	43%
4 = good knowledge	22%
5 = excellent knowledge	8%

Table 2 tabulates the respondents' objective awareness levels of CSR. Of the 19 CSR activities, listed, social awareness campaigns (24%), corporate volunteering (43%) and employee wellbeing (51%) represented the activities that respondents felt least likely to constitute a CSR activity. Greater use of renewable items (92%), assessment of the business impact on society (89%), risk management (89%) and philanthropy (89%) were the activities the respondents felt most likely to represent a CSR activity.

Table 2. Distribution of objective awareness levels

Ref	CSR Activities	Yes %	Frequency			Rank
			Yes	No	Don't Know	
1	Greater use of renewable items	92%	34	3	0	1
2	Assessment of business's Impact on society	89%	33	4	0	2
3	Philanthropy	89%	33	3	1	2
4	Risk management	89%	33	4	0	2
5	Openness in reporting	86%	32	5	0	5
6	Environmental awareness	86%	32	2	3	5
7	Community engagement projects	84%	31	5	1	7

9	Social procurement strategies	81%	30	6	1	8
8	Training & education of employees	78%	29	5	3	9
11	Stakeholder management	76%	28	7	2	10
10	Sustainable supply chain practices	73%	27	7	3	11
12	Environmental responsibility	68%	25	5	7	12
13	Environmental management tools	65%	24	4	9	13
14	Reputation management	57%	21	10	6	14
16	Product/technique innovation	54%	20	11	6	15
15	Employee wellbeing	51%	19	8	10	16
17	Providing a good work-life balance for employees	51%	19	12	6	16
18	Corporate volunteering	43%	16	21	0	18
19	Social awareness campaigns	24%	9	21	7	19

Correlation analysis between the subjective awareness and objective awareness levels showed that there is a positive correlation between the two measures, 0.460. It must be realised that 19 CSR activities for the objective awareness category cannot cover CSR in its entirety. The purpose of including an objective measure was to make sure the subjective awareness levels were both consistent and reliable. The results indicated as such. These results were to be expected as most the participants had more than 10 years working experience in the industry and were assumed to hold positions of authority in their respective companies. Therefore, only the subjective awareness was used to test whether the objectives were met.

CSR implementation levels

Table 3 below tabulates the respondents' implementation level results for the three CSR components.

Table 3. CSR component implementation levels

CSR components	Component points		Descriptive statistics					
	Total points available	Converted per formula	Mean points scored	Median	Min	Max	Std. Dev.	Skew.
Environmental implementation	10	1	0.56	0.58	0.13	0.98	0.22	-0.07
Social implementation	8	1	0.65	0.63	0.28	0.97	0.13	0.45
Ethical implementation	8	1	0.73	0.75	0.38	1.00	0.18	-0.25
Overall implementation	26	1	0.65	0.62	0.42	0.96	0.12	0.57

The overall environmental implementation scores for the 10 questions showed that the participating companies incorporated just over half of the policies identified (mean 0.564; median 0.575). The range between the minimum and maximum values was however very wide, 0.850, as the lowest score was 0.125 and the maximum score was 0.975.

The social CSR component comprised seven questions covering the basics of social responsibility in the construction context, for example, the provision of protective clothing and recording of all work-related accidents, etc. Again, companies were found to incorporate over half the policies identified into their business operations (mean 0.648; median 0.625). The range the social aspect of CSR was slightly narrower, 0.688, as the lowest recorded score was 0.281, with the maximum score being 0.969.

The ethical component of CSR consisted of eight questions. These questions included controversial topics such as fraud, negligence, payment issues, etc. Due to the nature of the questions, care was taken to ensure that these questions were precisely worded to make the participants feel as though they could respond openly. Questions were framed as "have you ever witnessed or experienced a particular scenario" rather than "Have you or your company ever been involved in a particular situation". With this being said, the ethical component in this study identified industry level incorporation rather than at company level. Unsurprisingly, the total implementation level was considerably higher than that of the environmental and social aspects (mean 0.733; median 0.750).

With regard to the overall incorporation of CSR policies, there was an adequate level of implementation (mean 0.648; median 0.628), the lowest recorded score being 0.419 and the highest score being 0.965.

The wide range in implementation levels for both the environmental and social CSR components reinforced the literature stating that a company's implementation levels will differ significantly regarding the environmental, social and ethical components of CSR.

Non-parametric correlation analysis between variables

Table 3 displays the results of the non-parametric correlation analyses. The awareness level was found to be positively correlated with the environmental implementation component (0.596). The awareness level was furthermore positively correlated with the social implementation component (0.543), both significant at 5% level. Table 3 represents the results of the correlation analyses between the respective CSR components.

Table 3. Non-parametric correlation analysis (Spearman's *p*) between variables

Variables	*Env. Imp.*	*Soc. Imp.*	*Eth Imp.*	*Overall Imp.*	*Economic concern*
Awareness	0,596°°	0,543°°	0,177	0,652°°	-0.282
Environmental Imp.	-	0,462°°°	0,462	0,781°°°	-0,04°°
Social Imp.	-	-	0,093	0,689°°°	-0,106
Ethical Imp.	-	-	-	0,538°°°	0.103
Overall Imp.	-	-	-	-	-0,009
Note: °,°°,°°° Correlation is significant at the 0,10, 0,05 and 0,01 level (two tailed)					

CSR awareness level was positively correlated (0.177) with ethical implementation. Again, the ethical implementation only represents industry level implementation and not company level.

Therefore, it is reasonable to assume that a company's individual awareness scores are not correlated with that of the industry as a whole.

The general level of CSR awareness level was positively correlated with overall CSR implementation (0.652), as can be seen in Table 3. Therefore, the higher the awareness level of CSR, the greater the level of CSR implementation (Objective one). This finding confirmed what was previously found in the literature that if CSR awareness can be increased in SME's, implementation levels will increase. This idea is confirmed by Chiveralls *et al.* (2012) who suggest that the main obstacle to CSR adoption in SME's is a lack of awareness and understanding of the concept. The result is that Everett Roger's diffusion paradigm applies to the concept of CSR awareness and implementation.

With regards to economic concerns and their effect on overall CSR implementation, there was a negative correlation (-0.009). This suggests that there was a cost concern regarding CSR implementation (Objective 2). The majority of the respondents (67.6%), regardless of their level of implementation, ranked the economic aspect of CSR as the most important, yet this does not prevent them from incorporating specific environmental, social or ethical CSR aspects into their business operations. So, whilst the cost of CSR does affect implementation levels, SMEs still implement some CSR components into their operations.

The findings resulting from this paper should not, however, be used to refute the law of demand, as CSR is complex in both its scale and measurement. CSR implementation therefore cannot simply be related to cost, as numerous other variables affect implementation levels. Research conducted on the relationship between CSR and financial performance has produced conflicting results. While some argue that CSR results in valuable benefits such as employee satisfaction and increased company recognition (Galbreath, 2010), others believe that no beneficial relationship exists between business success and incorporation of CSR components (Lucas, Cunningham & Lamberton, 2009). The results of this paper provide added insight into CSR implementation in SMEs.

CONCLUSION

The two objectives of the study were to identify the relationship between SMEs' awareness and implementation levels of CSR, and to identify the relationship between SMEs' concerns towards the costs involved in implementing CSR initiatives and their level of implementation of CSR.

Traditionally CSR has focused on larger companies due to both their public presence as well as the enormity of their operations. However, SMEs tend to be forgotten when it comes to CSR. Researchers such as Moyeen and Courvisanos (2012) believe SMEs face more challenges than their larger counterparts in implementing CSR activities, as they often lack the financial resources and have fewer opportunities to gain from the benefits of participating in CSR. Both Santos (2011) and Chiveralls *et al*. (2012) believe that strategies undertaken by SME's to implement CSR are highly informal and that one of the main barriers to adoption of CSR practices was a general misunderstanding and lack of awareness of the matter.

This lack of awareness and understanding of CSR by SMEs provided the premise for the first objective. When asked to rank their understanding of CSR on a "5-point" Likert Scale, 43% of the respondents stated they were moderately knowledgeable about CSR while 27% of the

respondents had a poor CSR knowledge level. Unsurprisingly only 8% of the respondents claimed to be very knowledgeable (Level 5 on the Likert scale) when it came to CSR.

An objective measure was used to test the reliability of the subjective awareness levels. A positive correlation between the two awareness levels meant that the subjective awareness levels were reliable.

The moderate knowledge levels of CSR was in line with Chiveralls *et al.* (2012), who believe that SMEs seldom incorporate CSR into operations due to their misunderstanding of the practice. This moderately low knowledge level of CSR by the respondents also resonates with Everett Rodgers' Diffusion of Innovations concept, which states that for a particular idea/concept to be implemented it must first be recognised by the individual.

About the implementation levels of the individual CSR components, as well as the overall implementation levels, there was an adequate level of implementation (mean 0.648; median 0.628), the lowest recorded score being 0.419 and the highest score being 0.965.

The wide range in implementation levels for both the environmental and social CSR components reinforced the literature suggesting that companies' implementation levels differ significantly regarding the environmental, social and ethical components of CSR.

The effect of awareness on implementation levels of CSR was found to be profound, as suggested by Jenkins (2006) and Santos (2011), as the correlation between the general level of CSR awareness level was positively correlated with CSR implementation (0.651, significant at 5%). Therefore, the higher the awareness level of CSR, the higher the level of CSR implementation, so Objective 1 of the study was deemed to be met. This finding confirmed what was previously found in the literature that if CSR awareness can be increased in SMEs, implementation levels could increase.

As the literature suggests, the construction industry is notorious for the slow adoption of alternative procedures unless there is a clear business case for doing so. This is particularly true for CSR in construction. There has been an increase in the demand for accountability of the construction sector participants, as the CI has a significant impact on both society and the environment at large.

The literature highlights the fact that SMEs very rarely formally engage in CSR. SMEs tend to approach CSR in a highly informal and practical manner. Moyeen and Carvisanos (2012) believe that SMEs adoption of CSR practices is done in alignment with business strategy, therefore suggesting that SMEs' approach to CSR has a business motive.

Economic concern about CSR provided the premise for the second objective. When asked to rank the importance of the four economic aspects of CSR, namely: economic, environmental, social and ethical, economic responsibility was ranked the most important by 68% of the respondents. The respondents' concern about the cost of CSR was then used along with the implementation scores of the components, as well as overall implementation levels. To determine whether economic concern about CSR had a negative effect on implementation levels. Negative correlations were found to exist between the economic concern and the environmental, social and overall implementation levels. A negative correlation of -0.009 between economic concern and overall implementation levels suggests that economic concern about CSR does effect implementation levels; however the economic concern does not prevent

SMEs from incorporating some CSR initiatives into their business operations. The results of the study resonate with Horvat (2015: 345), who suggests that the misconception that CSR is expensive to incorporate often hinders implementation levels of CSR in SMEs. Therefore objective 2 was deemed to be met.

With regard to the study, it was found that SMEs' awareness levels were positively correlated with implementation levels, therefore suggesting that if awareness of CSR can be raised, implementation levels could increase. The study also revealed that economic concern might have prevented SMEs from fully engaging in CSR but does not prevent SMEs from incorporating aspects of CSR into their business operations.

The results of this study provide further evidence of a neutral relationship, yet should not be considered conclusive as further research is required to examine the relationships theoretically and test them empirically.

This study aimed to help generate awareness concerning CSR in South African construction SME's. With an increase in knowledge of CSR, SME's would be able to incorporate their CSR initiatives into business operations, thus realising benefits for both the business and broader communities.

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KEY ENABLERS IN THE CSR/BUSINESS STRATEGY INTEGRATION SPACE

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Keywords: Corporate Social Responsibility, Sustainability Reporting, Triple-Bottom-Line, CSR Education

Abstract

Despite the potentially positive image and reputation implications of businesses implementing strategies in Corporate Social Responsibility (CSR), there appears to be a dearth of companies willing to play a leading role in advancing CSR activities to upper levels within the consciousness of the organisation. The vast majority of businesses appear to be merely complying with national regulations in their business sustainability efforts. The aim of this study is to investigate the key enablers in assisting businesses integrate their corporate social responsibility with their business strategy. A 17question online survey was administered to a number of national and global businesses in a range of industries. The resulting qualitative and quantitative data from 86 respondents was analysed and is presented in tabular, graphical, and text form. Quantitative responses were presented in the form of descriptive statistics while qualitative data was analysed and presented thematically. The study found that the three main enablers to businesses integrating CSR with their corporate strategy were (i) leadership in the CSR area, particularly at senior management level (ii) informed education/knowledge in all aspects of CSR, (iii) better measuring techniques for measuring CSR outcomes. Both academia and the business world can contribute and assist in confronting the three main issues and guide businesses as they attempt to integrate CSR with the strategy of their organisation. The study should help to guide business and engineering schools in designing academic programmes to include CSR learning outcomes to their programmes.

INTRODUCTION

Evaluation of the role of business in society has developed over the past couple of decades. Accountability and transparency in all aspects of business activity has augmented terms such as Corporate Social Responsibility (CSR), Corporate Responsibility (CR) and Corporate Citizenship (CC) into the business consciousness (Aspling, 2013, p 46). This new reality has forced businesses to reconsider their role and duties in society and in the wider economic community. Catalin and Nicoleta (2011) claim that the overall concept of sustainable development, that includes CSR, CR, and CC, emerged as an alternative philosophy to the neoliberal school of thought which has dominated economics for the past three decades, which argues for markets to be free with little or no intervention by government. This economic agenda was promoted by Ronald Reagan and Margaret Thatcher in the 1980's. This neoliberal economic theory is growth-driven and while it is probably a fairly robust business growth model, continuous growth has put pressure on our vast but finite natural resources causing environmental degradation which, according to Catalin and Nicoleta (2011), can threaten our

wealth and even our existence. In this study, key issues are identified that, if embedded into the business culture, enables businesses to embrace the new sustainability reality.

While CSR appears to be an ambiguous concept (Roszkowska-Menkes, 2016), there is a consensus in published literature that it can be generally thought of as a strategic level management decision-making platform that considers financial, human, and environmental issues in their business decisions (Wang, 2015). On a similar theme sustainable development is often defined as 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. This definition emerged from the Bruntland Commission which was set up by the United Nations (UN) (http://www.un.org) in 1983. Their mission was to direct sustainable development on a global level. The process of globalisation opens up new unprecedented opportunities of large scale redistribution of wealth and in such actions, humanity itself becomes increasingly interconnected. The UN subsequently initiated eight international development goals in the year 2000 entitled the UN Millennium Development Goals, and the objective was to reach these goals before the year 2015. Along with the eight goals, there were 21 targets and a series of measurable indicators to assess if the sustainability targets were being met or not. Questions remain as to whether the UN Millennium Development goals have been reached (Sandbu, 2015). A follow-on framework was put in place with the setting up of the Sustainable Development Goals (SDG) to cover the 15-year time period between 2015 and 2030. The new proposal contained 17 goals and 169 targets. Implementation of the structures to ensure that the goals are achieved was discussed at the 2015 United Nations Climate Change Conference (COP21) held in Paris between 30th November and December 11th 2015. There is much input from a variety of stake-holders regarding the topic of climate change and environmental degradation and one such contributor is Pope Francis (2015) who claims that we need to examine the causes related to human and social degradation in tandem with the causes relating to environmental degradation. He also claims that religion and science, with their distinctive approaches to understanding reality, can enter into an intense dialogue fruitful for both (Pope Francis, 62. P37). The questions in the survey probe the topics of governmental influence, faith, sustainability reporting, leadership and education in the context of sustainable business development. The area of CSR is generally considered to belong to the discipline of Management (Wang, 2015). This study seeks to determine if businesses have actually bought into these aforementioned facets of business management and if not, then the road-blocks to such sustainable business development are identified.

LITERATURE REVIEW

Overview

In the business community, it appears that the term 'sustainable development' is 'nebulous and contested' as stated by Sandelands and Hoffman (2008) with a general acceptance that the more familiar Corporate Social Responsibility (CSR) term falls under the remit of sustainable development (Kealy, 2014). Kealy (2014) acknowledges that CSR is an important element in corporate management practices and if properly understood, CSR encompasses the wider sustainability components sometimes labelled the three 'P's', as suggested by Elkington (1997), namely Profit, People and Planet, and this is only achievable by having capable leaders with a

‘clear strategic vision who are guided by a strong ethical/moral compass’ (Kealy, 2014). From the previously stated definitions of CSR and sustainable development, all three components (Elkington, 1997) must be considered in business management decisions (Fig. 1). Of the three elements in Fig. 1, financial reporting is the most established entity. The financial report gives periodic (quarterly, half-yearly or annually) details of the financial activities and position of a business. The other two non-financial (human and environment) reporting frameworks are less well established. As a result of the changing global landscape a number of standards (e.g. the UN Global Compact, the OECD Guidelines for Multinational Enterprises, the Global Reporting Initiative, Origin Green) have emerged to help corporations implement, manage and report their CSR activities (Vigneau et al. 2015). Issues surrounding the completion of such sustainability reports is analysed in this research.

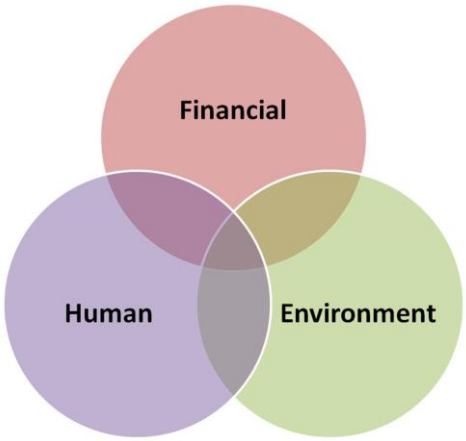

Fig. 1 Main elements of sustainable development/CSR model (Elkington, 1997)

Research by Pless et al. (2012) and Waldman (2011) also implies that leadership is essential for advancing the challenges and demands associated with the integration of CSR activities within a firm. However, Pless et al (2012) suggested that managers interpret and display leadership in many different ways and this may contribute to the lack of evidence that leadership have on firm-level and societal-level outcomes.

The research findings by Kealy (2014) concurs with claims by Aspling (2013, p 45) that the majority of businesses are rooted at the lowest phase or level of development of a conceptual framework identifying how to integrate global responsibility with the strategy of the organisation (Fig. 2).

Fig. 2 Three levels of business sustainability efforts (Aspling, 2013, p 47)

Aspling (2013, p 46) claims that, at the lower end of the model, compliant businesses are doing the minimum to comply with regulations, the strategist business reports voluntarily and strives for sustainability rankings while the top level, the futurist businesses, engages in responsible action for the common good as an explicit part of their mission.

Global Sustainability Initiatives

In terms of global business sustainability initiatives, the United Nations (UN) launched the Global Compact initiative in 2000 to encourage businesses worldwide to implement sustainable and socially-responsible policies and report on their implementation. The Global Compact (http://www.unglobalcompact.org) is based on ten guiding principles, covering the areas of human rights, labour, the environment, and anti-corruption. The two objectives of the UN Global Compact are to (i) mainstream the ten principles in business activities around the world, and (ii) catalyse actions in support of broader UN goals, such as the eight Millennium Development Goals, targeted for completion by 2015. There appears to be some criticism to the UN Global Compact initiative and based on the evidence presented in Fig. 2, it appears that the initiative has not had the desired effect on global businesses. Some of the criticism stems from the fact that the Global Compact is not a regulatory instrument and so has no enforcement provisions, thereby rendering it ineffective in holding businesses accountable. It appears to operate more like a discussion forum which can leave itself open to misuse by businesses who can promote themselves as sustainably-responsible businesses without actually making any significant change to their strategic efforts (Milne and Grey, 2013). Luthra et al. (2018) identified the key issues that influence sustainability initiatives to be implemented in global businesses. The three most prominent issues identified were (i) government support systems, (ii) knowledge and awareness of sustainability tools, and (iii) information systems network design.

CSR/Sustainable Development Business Initiatives in Academia

CSR/Sustainable Development concepts have originated mainly within the discipline of management (Carroll, 1979; Wang, 2015). The CSR theme has been explored from various management perspectives such as social obligations, marketing, stakeholder-relation, integrated strategy and leadership themes. The leadership theme focuses on the ability of business leaders to build relationships with a number of stakeholders to advance an effective shared business vision (Wang, 2015). Academia and Business Schools in particular have a major role to play in helping to foster and develop such merits in their future leaders. The UN appear to concur with this vision and in 2004 the UN Global Compact (along with the European Foundation for Management Development, http://www.efmd.org) formed the 'Globally Responsible Leadership Initiative' (GRLI). The GRLI (http://www.grli.org) seeks to influence and guide academia so that business schools mission, strategy, and activities show evidence of its contribution to ethics and sustainability. It is a worldwide partnership of companies and business schools working together to develop a next generation of globally responsible leaders. It may be that it is not enough that business schools limit their curriculum to the traditional core business disciplines of Marketing, Accounting, Strategy, Finance, Management and Economics but imperative that they also include embedded modules on sustainable development/corporate social leadership (Seto-Pamies and Papaoikonomou, 2016). A hypothesis of this study is that there is a need to include CSR/sustainable development modules in business school curriculum with a major focus on non-financial reporting (human and environmental aspects in Fig. 1). Research by Medina Rivilla and Medina Dominguez (2014) suggested sustainable development requires a better and more fruitful interface between academia and the business world. They recommend that learning institutions focus on competencies such as leadership, planning, management, communication, motivation, methodology, resource optimisation, collaboration, innovation, inquiry, reflection, and empathy and that lecturers must be prepared to assist in creating an environment conductive to entrepreneurship. Research by Smith and Ronnegard (2016) examines the shareholder primacy norm (SPN) as a widely acknowledged impediment to CSR. Smith and Ronnegard (2016) suggest that SPN may be part of the manager's legal fiduciary duty that possibly requires them to make decisions that further the interests of the shareholders which stems from a largely unquestioned adherence to shareholder theory in business schools. The efforts of the GRLI initiative are certainly not apparent judging by the comprehensive report in 2014 by the Boston Consultancy Group (BCG), MIT Sloan Management Review and the United Nations Global Compact entitled 'Joining Forces: Collaboration and Leadership for Sustainability'. Of the 3,795 senior and middle managers from 113 countries interviewed, only 20 per cent of respondents believe that their senior level executive boards provide substantial insight on sustainability issues. The report goes on to say that one of the strongest barriers to greater executive level engagement is a lack of sustainability expertise among board members. If this is the case, then perhaps a better and more fruitful interface between academia and the business world, as suggested by Medina Rivilla and Medina Dominguez (2014), would assist in developing the tools required by business leaders to address sustainability issues.

METHODOLOGY

The study aimed to target a cross-section of businesses with a deep-rooted interest in Corporate Social Responsibility (CSR) who reside on national (Irish) and international sustainability reporting databases. A survey research methodology was used in this study where data was obtained using an on-line questionnaire. The survey used standardised questions that emerged following an extensive review of the literature. Qualitative and quantitative data was generated from the survey using closed type and open type questions. This research approach was chosen because it is felt that it could obtain pertinent data from a large sample that may assess possible reasons as to why businesses appear to be having difficulty integrating corporate social responsibility with the strategy of the organisation as described by Aspling (2013) in Fig. 2. The on-line survey method minimised the complexities of administering a questionnaire across different geographical locations to businesses participating in this research. The questions were focused on important management aspects within industry as identified in the literature. The 17-question survey was designed using simple and clear language in order to minimise the potential for ambiguity by the survey respondents. Prior to administering the survey, an initial pilot questionnaire was sent to a number of CSR practitioners and academics in order to ensure validity and reliability of the tool used. Quantitative responses were presented in the form of descriptive statistics while qualitative data was analysed and presented thematically. Thematic analysis is a means of analysing qualitative data in a rigorous and methodical manner (Nowell et al. 2017). Thematic analysis was utilised by developing codes from the survey data (Braun and Clarke, 2006). The coding process allows for the simplification and focus on pertinent characteristics within the data. Subsequently, themes are developed from the interpretation of the codes. Classified themes are used to identify patterns that underlie the themes. In total there were 394 business contacted (national and international) with 86 completing the survey on-line. This gives an overall completion rate of 22%.

RESEARCH RESULTS

Profile of Respondents (Quantitative data)

Manufacturing businesses, at 29%, have the highest percentage of all the industrial sectors to have responded to the survey. Based on content analysis on company websites, it appears that manufacturing businesses are very keen to impact the company's image and promote themselves as behaving in an ethical and responsible manner in all the processes required for the manufacturing operations. It is also noticeable that each business encourages their supply chain to also act in an appropriate high standard in respect of their corporate social responsibility. Other industries that appear to have significant CSR focus, according to company listings on sustainability databases and who contributed to this research are Agriculture/Forestry/Fishing (16%), Utilities (6%) and Finance/Insurance (6%). There is an even spread of company size in terms of the number of people employed by the company. The participants include small businesses, Small-Medium-Enterprises (SME), large industries and Multi-National-Corporations (MNC's).

Of the 81 respondents to the management level question, it was noticeable that only 24 respondents (30%) operated at top management level. The management level at which most respondents operated, 43 in total, was the middle management level (53%). The remaining 14 respondents (17%) stated that they were neither of these categories but were advisors, CSR consultants, project managers, analysists, and business owners. In the UN/BCG 2014 Report, only 20% of the 3,795 senior and middle managers interviewed believed that their senior level executive boards provide substantial insight on sustainability issues. Research by Waldman et al (2006) examines the relationship between (transformational) leadership style with the CSR values held by a company and one of the findings was that whatever vision the CEO had of CSR had an impact on the lower level managers' view of CSR. Thirty-two of the 86 respondents (41%) had between 1 years and 5 years' experience in a CSR role and 11 (14%) had less than one years' experience. These values may indicate that either (i) CSR has a renewed prominence within businesses as 55% of participants had 5 years' experience, or lower, in their CSR role or (ii) newer members of staff are delegated this role. While the earliest seminal piece of CSR literature was produced by Bowen (1953) and publications in the area increased rapidly through the following decades (Carroll, 1999), there appears to be renewed interest in the CSR area. This may be due to some recent highprofile corporate ignominies of which the global public can be cognisant mainly because of the (social) media information age. One such ignominy is the Volkswagen (VW) emissions scandal (Wearden, 2015).

The question was asked about the level of CSR engagement at which the participant perceived their company to be operating. The three levels are graphically identified in Fig 2. There are a number of possible factors that influence the level of CSR engagement (Hu et al. 2018) among which is the type of business ownership and whether the business is listed on the Stock Exchange.

Table 1 Levels of CSR engagement based on Graphical Description in Fig. 2

Q. Which of the following levels of engagement best describes your Corporate Social Responsibility/Sustainable Development activities within your organisation?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Upper level:	51	59.3	66.2	66.2
	Middle level:	17	19.8	22.1	88.3
	Lower level:	7	8.1	9.1	97.4
	None of the above	2	2.3	2.6	100
	Total	77	89.5	100	
Missing	System	9	10.5		
Total		86	100		

Of the 77 respondents to this question, the majority of these (51) perceive themselves as engaging on the upper level of CSR activities as shown in Table 1. There are 9 respondents that did not answer this question (Missing). These respondent companies were selected based on national (Irish) and international sustainability reporting databases. All of the companies have their sustainability measures embedded on their websites and promote themselves as being responsible corporate citizens.

Most of the Irish-based respondent companies were aligned to the Origin Green framework (41%) and the majority of the UK and USA companies (41%) were aligned to the GRI reporting framework.

Of the 66 respondents to the question regarding the highest academic qualification held by the respondent an equal amount, 28 (or 42% each, 84% in total) had academic qualifications at Degree or Masters level. A total of 7 respondents had diploma level qualifications and 1 respondent had certificate level qualifications. Two of the 66 respondents had PhD qualifications. Twenty people did not answer this question.

Table 2 Location of academic training of participants

Q. Where did you complete your business academic training?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Other country (please specify)	2	2.3	3.1	3.1
	United Kingdom	21	24.4	32.3	35.4
	Ireland	31	36	47.7	83.1
	Europe (excluding UK and Ireland)	4	4.7	6.2	89.2
	United States of America	7	8.1	10.8	100
	Total	65	75.6	100	
Missing	System	21	24.4		
Total		86	100		

The majority of the 65 respondents to this question, 31 (48%) completed their academic training in Ireland. The two respondents who selected 'Other' completed their academic training in the UK, France and Australia. Twenty-one respondents choose not to answer this question (Missing). There was an even spread of the time period for their most recent academic training by the respondents – 17 within the last two years (26.2%), 15 between two years and 5 years ago (23.1%), 17 between 5 and 10 years ago (26.2%), and 16 more than ten years ago

(24.6%). Twenty-one respondents skipped this question. This means that 75.5% of respondents completed their most recent academic training within the last 10 years.

Table-3 Leadership Module on Academic Programmes?

As part of your academic training, did you complete modules on 'Leadership'?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	34	39.5	53.1	53.1
	No	30	34.9	46.9	100
	Total	64	74.4	100	
Missing	System	22	25.6		
Total		86	100		

Of the 64 respondents to this question, 34 stated that they had taken leadership modules as part of their academic programme but almost as much again, 30, stated that their academic training did not include leadership modules. Surprisingly, 22 (over a quarter of the respondents) did not answer this question. Leadership was identified in the literature as being very important for championing CSR issues within businesses (Pless et al. 2012; Waldman 2011).

Table 4 Geographical areas for 'Leadership' Modules on Academic Programmes

	Leadership Modules on Academic Programme	
Academic Training in -	Yes (%)	No (%)
Ireland	65	35
UK	37	63
USA	57	43
Europe (Exc Irl & UK)	50	50

Graduates who completed their academic training in Ireland are most likely (65%) to have undertaken leadership modules as part of their academic degree programmes based on the results shown in Table 4.

Table 5 CSR Module on Academic Programmes?

As part of your academic training, did you complete modules on 'Corporate Social Responsibility/Sustainable Development'?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	28	32.6	43.8	43.8
	No	36	41.9	56.3	100
	Total	64	74.4	100	
Missing	System	22	25.6		
Total		86	100		

Of the 64 respondents to the question of completing a CSR/Sustainable Development module as part of their academic training, 36 replied that they had not done so (41.9% in Table 5). 28 respondents stated that they had done so (32.6%) and 22 people skipped this question (25.6%). None of the USA respondents had completed modules on CSR/Sustainable Development as part of their academic programmes.

There were 60 respondents (out of 86) to the question of the potential for a faith-based input as a positive influence to sustainable business development. The majority of these (46 or 76.7%) stated NO while 14 respondents (23.3%) stated YES. There was a significant number (26) of respondents who skipped this question. While some respondents felt that a faith-based input (such as Catholic Social Teaching) could be 'very helpful when combined with an overall programme in ethics/philosophy' (Respondent #3), others suggested 'it could be positive or negative' (Respondent #13). Another issue that emerged was the possibility of risk in introducing faith into business practices. The risk is that 'it would be difficult to work with faith-based organisations that are non-affiliated and inclusive enough to meet the needs of our diverse stakeholders' (Respondent #1), sometimes covering a number of countries and cultures for global multinational businesses. One of the respondents claimed that 'the tenets of the Judeo-Christian religion that have actually formed most western thoughts and actions, and in a business context they can be a powerful force for good, positive social and environmental behaviour' (Respondent #11). Pope Francis (2015) also claims that a combination of religion and science can benefit each other as solutions to our current environmental, and human, degradation are sought.
Five respondents contributed additional comments at the end of the survey where CEO commitment and CSR skills and training were again part of the pertinent issues specified.

Open-ended Questions (Qualitative Data) Advantages Associated with Sustainability Reporting
Some literature claims that there are potential advantages (de Villiers et al. 2016) associated with reporting on sustainability issues (both financial and non-financial) within their business. As a result of the coding process on the data obtained from the responses to the 'advantages associated with sustainability reporting' question, the main issues were identified as follows: Stakeholder Engagement (external) [SE] – Improvement [IM] – Regulation [R] – Human (internal) [H] – Ethics [E] – Strategy [S] – Top Management [TM] – Marketing [M]. A total of 41

respondents contributed to this question. The most common issue was stated as the Improvement [IM] component to sustainability reporting (18 respondents out of a total of 41 mentioned this when replying to this question). The advantageous issues that arose as a result of the coding process are listed as follows:

- Improvement [IM] 18/41
- Stakeholder Engagement [SE] 15/41
- Human (internal) [H] 12/41
- Strategy [S] 10/41
- Regulation [R] 10/41
- Ethics [E] 7/41
- Marketing [M] 5/41
- Top Management [TM] 2/41

The most common advantageous issue that was associated with a business implementing a sustainability reporting process was the fact that the business could use the values in the report to improve performance in future years, 'provides ongoing data for which continuous improvement plans can be designed and measured' (Respondent #1). It was also stated that there was more stakeholder engagement due to the reporting process, 'way of communicating with our stakeholders about our values' (Respondent #14). The completion of this report requires input from a number of stakeholders and the more stakeholders that become involved in the process, potentially the more benefits there will be accrued by the business. This positive aspect includes both internal, 'supports employee retention/recruitment' (Respondent #4) and external stakeholders, 'more of our customers are looking for products produced responsibly' (Respondent #34). A business with a strong CSR culture can use the ethos for 'alignment with business development strategy' (Respondent #21). CSR 'promotes and encourages an ethical ethos throughout the company' and 'fosters good corporate governance' (Respondent #30) and CSR 'helps with B2B sales' (Respondent #41).

Disadvantages Associated with Sustainability Reporting

Some literature claims that there are potential disadvantages (Bekefi and Epstein, 2016) to embracing sustainability reporting within a business. In-depth analysis of the data identified time as one of the disadvantages to sustainability reporting and this is shown in Fig. 3. The word 'time' is the subject of the text search and shows how respondents described some of the disadvantages associated with sustainability reporting are how they are explicitly linked to the word 'time'.

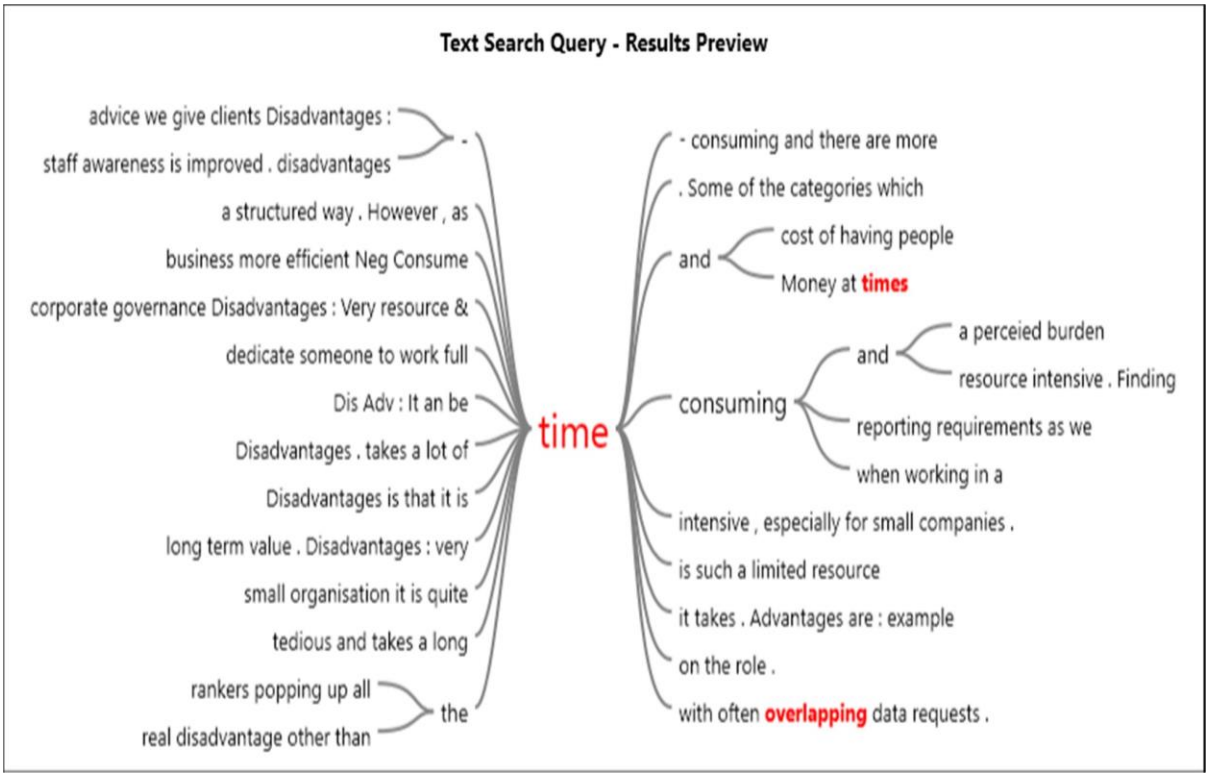

Fig. 3 Word Tree with 'time' as the Subject

The disadvantage of committing a company resource (time) to completing the sustainability report (usually annually) was one of three company resource factors seen as a disadvantage to sustainability reporting, the other two being a human resource and a financial resource. The full list of issues that developed as a result of the coding process for this 'disadvantages' part of the question is as follows:

- Non-Standard Reporting [NS] (7 respondents out of a total of 28 mentioned this in their response: 7/28)
- Surface Effects [SF] (3/28)
- Resources (Time) [RST] (15/28)
- Resources (Human) [RSH] (3/28)
- Resources (Financial) [RSF] (3/28)
- Complexity [CX] (5/28)
- Measurement [M] (2/28)

The disadvantage of not aligning sufficient resources to implement the sustainability reporting process effectively is a major issue identified in this study, 'time-consuming reporting requirements as we do not have someone solely hired for environmental/CSR/Sustainable Development' (Respondent #42). If CSR is to be a strategic issue within a business, then it is surely incumbent on top (senior level) managers to align sufficient resources to complete the job properly. This may include allocating a larger portion of company time, human, and financial resources to CSR-related activities, 'very resource and time intensive, especially for small companies' (Respondent #30). The lack of a cohesive approach to sustainability reporting highlighted by Xu et al. (2016) was evident in the responses to this part of the survey also, 'the lack of a structured approach to data gathering in line with a sustainability framework means

it is more challenging' (Respondent #2). The 'cost and complexity and a lack of common standards within and between industries' were identified as a disadvantage to sustainability reporting (Respondent #5).

Level of Support for CSR Duties

Of the 54 respondents to the question of support for CSR duties, 23 stated that they had positive, top management, support as they carried out their CSR duties, 'we have the full support from the Board and the Executive' (Respondent #17). Only 6 out of the 54 respondents had a low level of support and 3 respondents stated that they would receive support if the CSR activities were deemed to be profitable, 'support is generally available if the sustainability team can be seen to be adding value and not just introducing something that does not add anything to the business' (Respondent #12).

Governmental Involvement in Promoting Sustainable Business Development

There were 50 respondents to the question as to whether governments should be more actively involved in promoting Sustainable Business Development and the vast majority (90%) stated YES and a minority (10%) stated NO. The respondents were encouraged to submit other comments on what level of governmental involvement, if any, they wish to see in assisting businesses in the CSR/Sustainable Development area. Comments were made that 'governments can and should legislate to prevent the most negative impacts a company may have on society e.g. environmental' (Respondent #2). Governments can also 'help to set the minimum standards expected and provide avenues/grants/regulation to encourage leadership and innovation' (Respondent #5). There was also a suggestion that 'sustainable business development should be a careful balance of Public/Private Partnership' (Respondent #11).

Barriers to Integrating CSR and Business Strategy

The main issues that emerged as barriers to a business integrating CSR into its strategy were identified as follows:

- CSR is Expensive [EX] (20/50)
- No Stakeholder Priority [NS] (15/50)
- Education [ED] (8/50)
- Time Resource [TM] (8/50)
- Difficult to Measure [DM] (6/50)
- Lack of Leadership [LL] (5/50)
- Profit Driven [PD] (4/50)
- Lack of Governance [LG] (1/50)

Prior published literature in the CSR barriers theme identified key barriers to the implementation of CSR in businesses in Poland (Andrejczuk, 2016). Two of the key barriers to the implementation of CSR were (i) the belief that CSR 'does not pay off' and brings no benefits and (ii) a lack of education among managerial staff (Andrejczuk, 2016). These two findings by Andrejczuk (2016) concur with the findings of this study namely 'CSR is Expensive' (20 respondents out of a total of 50 mentioned this) and 'Education' (8 respondents). A sample of the responses included 'often the sustainable way is often quite expensive to implement or slightly more expensive than the alternative, it is also more time expensive' (Respondent #45).

One of the barriers was stated as 'a perception that sustainability is expensive and does not add value' (Respondent #11). Another barrier was a 'lack of understanding of the breadth of sustainability' (Respondent #7). Barriers included a 'lack of senior management buy-in' (Respondent #22) and a 'lack of clear leadership, vision, mission and non-aligned values' (Respondent #25). The measurement aspect of CSR was stated as a barrier because of a 'lack of metrics to measure impact of activities across all areas, including social' (Respondent #31).

DISCUSSION

Summary of Findings

The results of this piece of research would indicate that the majority of the participants found that a major impediment to an effective integration of CSR/Global Responsibility with the strategy of the organisation is that the reporting and disclosure of economic, environmental and social aspects of their management activities is perceived to be a time-consuming and challenging task. The comments by participants suggest that one of the difficulties is that there is a lack of a coherent analytical framework within and between industries by which they can report on all three elements of CSR (Fig. 1). Many of the businesses who participated in this research use the GRI reporting framework. While GRI is a well-established body, it is clear that completing the sustainability report is not a trivial task. There are significant volumes of data to be processed in order to complete the sustainability report accurately. There was a clear disconnect between the level of integration at which businesses are self-perceived to be operating (Table 1) and the level of integration at which research has found them to be actually operating (Fig. 2).

A second major finding in this study is that 56% of participants alleged that they did not complete modules in CSR/Sustainable Development as part of their degree programme. This is not in line with the UN/GRLI guidelines on mission, strategy, and activities within business schools set up to develop a next generation of globally responsible leaders. Considering that the GRLI was formed in 2004 and the majority of participants (75%) to this study completed their academic training within the last ten years it is disappointing that more progress has not been made to impel CSR into the mainstream academic arena. While the GRLI academic initiative is a step in the right direction, there appears to be a lack of policing of this UN/BCG initiative to convince more business schools to participate in propagating CSR modules onto their degree and Masters programmes. This finding concurs with the UN/BCG (2014) report which claims that one of the strongest barriers to greater executive level engagement is a lack of sustainability expertise among board members. This study found that one of the barriers to CSR advancement is the education barrier. As CSR is a wide-ranging topic, CSR education should not purely be confined to business schools but the area should be embedded into engineering and economic disciplines also. The study also found that 73% of participants believed that governments should have more influence in promoting and policing CSR/Sustainable Development activities within a firm. It was suggested that national governments should provide legislation and also provide grants to encourage innovation in the sustainability area.

Only 8% of respondents stated that governments should not have more influence in the CSR/Sustainable Development area. From these results, it appears that there is not much appetite for a free-market economy based on the views of current businesses who did partake in this study.

Other factors which may be contributing to the slow progress of companies integrating CSR within the strategy of the organisation (Fig. 2) may be the fact that more than half (53%) of participants, those with CSR responsibilities stated that they operated at 'middlemanagement' level within their organisation. Research by Beliveau (2013) and Kealy (2015) found that the main role of a middle manager was to implement deliberate strategy decided on by top, strategic level, managers. It would appear that managers at middle level find it difficult to enact change within the culture of the organisation. A lack of senior management buy-in to CSR issues within a firm is identified in this study as a barrier to strategy/CSR integration.

CONCLUSION

In conclusion, certain themes were identified, summarised as follows:

- Sustainability reporting is time-consuming and difficult. The process needs to be stream-lined with the inclusion of rigorous tests to verify claims made in measuring and evaluating sustainability initiatives. Discussion on the measures of the three sustainability dimensions (Financial/Human/Environmental) is ongoing
- Academic Institutions need to integrate CSR into their curriculum, namely into their Management, Engineering, and Economic disciplines
- Top management buy-in is of critical importance to CSR activities
- Strong and impartial government input is required to improve the rigor and robustness of CSR evaluation.

The findings of this research can be summarised by suggesting that the fragmented approach to CSR globally and nationally is partly due to (i) the sustainability reporting framework is time-consuming and difficult, (ii) a lack of education about the CSR components mainly because they are not generally taught on degree and Masters programmes in academic institutions. In order to improve the CSR outcomes it is recommended that a better and stronger government involvement is required to police both of these two weaknesses i.e. academic institutions' curriculum and also assessing and streamlining company sustainability reporting to validate that all claims are correct and honest and they are not just a marketing exercise to make the company appear like they are accountable corporate citizens. Until these impediments are addressed, it would appear that the vast majority of businesses will remain on the lower levels of the conceptual framework proposed by Aspling (2013) which identifies how businesses integrate corporate social responsibility with the strategy of the organisation.

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THE CIRCULAR ECONOMY IN UK CONSTRUCTION – WHAT ARE WE WAITING FOR?

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Keywords: circular economy, design, sustainability, waste.

Abstract

This paper considers the current setting for sustainability within the construction sector in terms of the legislative, social and technical contexts. It aims to promote a holistic discussion which covers the technical, systemic and logistical barriers to the adoption of Circular Economy (CE) principles by the UK construction industry. The CE concept is that products are re-used multiple times in distinct settings rather than used in a single setting then materially re-cycled or scrapped as waste. Adoption of the CE concept is recognised as being critically important to achieving the goal of a sustainable society, in 2016 the European Union made a legislative shift towards the CE concept by publishing the Circular Economy Package which introduces new EU resource management targets. The construction industry is a significant user of earth's non-renewable resources and therefore the construction sector plays a pivotal role in resource management and achieving sustainability. It is clear that the rate at which the UK construction industry is adopting CE principles is slow. Dramatic and positive strides have been made by both the demolition and construction industries towards reducing their contribution to landfill waste. However, much of this reduction is achieved either via downcycling, whereby the quality of the construction material is degraded, or via the use of significant quantities of energy in the re-cycling process. For example, concrete can be crushed and downcycled as recycled aggregate and steel from construction demolition is routinely melted down and incorporated into the production of new steel products. The construction sector should be making greater and more informed use of CE concepts, we should be designing in and deploying deconstruction techniques rather than demolition techniques, construction components derived from this deconstruction should be re-used rather than the derived materials being reprocessed, recycled or downcycled. How can we speed up adoption of a CE within construction?

INTRODUCTION

Sustainability and human impact on the environment have become headline concerns over recent decades. In recognition of the importance of these issues, significant positive strides have been taken within the construction industry towards increasing recycling rates and reducing both construction and demolition waste (Sustainable Concrete Forum 2017). However, this reduction in waste tends to be achieved predominantly via recycling of scrap material, for example scrap steel is routinely melted down as part of the steel making process and scrap concrete is crushed and used to replace stone and aggregate in road and foundation sub-base construction (Concrete Centre 2018). During this recycling process much of the

embodied energy within the steel or concrete is lost and additional energy is actually consumed during the recycling process (Allwood et al. 2010). The concept of the circular economy provides an alternative approach to material management through which embodied energy and embodied carbon can be preserved.

A Circular Economy (CE) is one in which "… the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised …" (European Commission 2015). This waste reduction is facilitated via re-use and repair of a given physical resource, rather than scrapping the resource at the end of each in-service phase. The traditional linear economy and circular economy approaches are compared diagrammatically in Figure 1. It can be seen that a linear economy is characterised by its single use nature following a path of: natural resource extraction, further energy consumption during the production and manufacturing phases, a single use phase then a decommissioning / scraping phase leading to the generation of waste material. Within a circular economy there is a much greater dependence on the re-use of components and re-use of materials, re-cycling of materials is demoted to having a last resort status. This diagram does not aim to provide the full picture, for example there is waste and / or energy conversion at each step in both types of economy, rather it aims to emphasise a shift in end of life scenario for the built environment and components used within it.

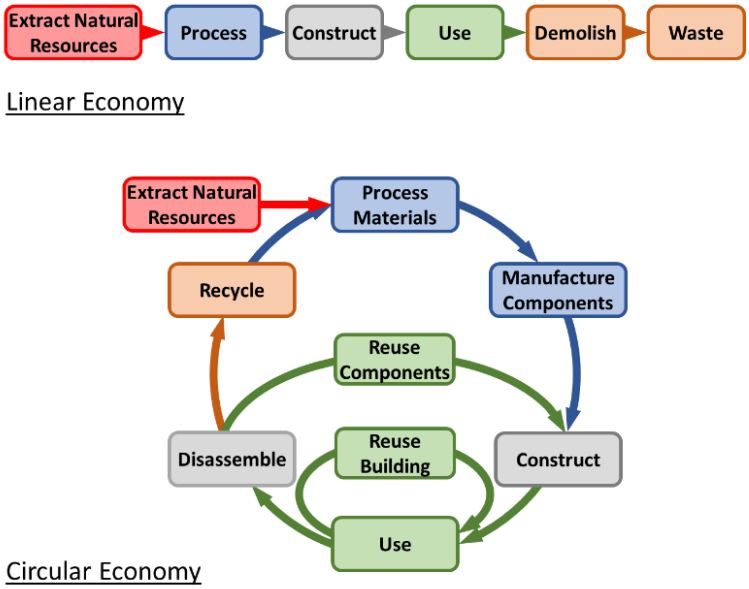

Figure 1- Linear economy versus idealised circular economy (After Crowther 2005)

CURRENT CONTEXT

Legislative Considerations

The UK Government has a 2050 target to reduce UK greenhouse gas (GHG) emissions by at least 80% compared with the 1990 baseline emissions, a commitment made in the 2008 Climate Change Act (UK Government 2008). In their Construction 2025 policy paper (HM Government 2013) the UK Government identify low carbon and sustainable construction as one of the three strategic priorities for the construction sector, the department for Business Innovation & Skills

have estimated that 47% of the total CO_2 emissions from the UK are influenced by the construction industry (Department for Business Innovation and Skills 2010). The GHG which has most impact on climate change and that has greatest scope for reduction by the UK construction industry is CO_2 (UK Government 2010). In their Low Carbon Routemap the UK GCB (Green Construction Board 2013) consider carbon emissions from UK construction to be broken down into two components: Operational Carbon and Capital (embodied) Carbon. Operational carbon broadly comprises GHG emissions from sources such as energy use, water use and waste whilst capital carbon in this context broadly comprises GHG emissions from the manufacture and production of construction materials and products. The GCB (Green Construction Board 2013) have reported a UK built environment baseline carbon emissions profile for the period 1990 to 2010. This baseline emissions profile shows the relationship between the embodied versus operational components to be approximately 18% versus 82%. GHG emissions from the built environment are currently dominated by direct emissions from space heating, which clearly justifies the focus that has been given to the design and construction of low energy use buildings in recent decades. However, as significant reductions in operational energy use in buildings can be achieved with relative ease, the role of embodied carbon within the built environment, and therefore the construction industry, will become increasingly important to achieving the target 80% reduction in UK GHG emissions. In their Low Carbon Routemap for achieving the government's 2050 GHG target, the GCB project a 66% reduction in embodied carbon within the built environment. The majority of this reduction comes from improvements in material extraction, manufacturing and production. Clearly material technology is therefore expected to have a major role to play in achieving the government's 2050 goal for GHG emissions. In the UK, concrete and steel are the dominant materials in terms of embodied carbon within the construction industry. The department for Business Innovation & Skills provide estimates for the volume of annual CO_2 emissions that can be attributed to various aspects of the UK construction industry, their report suggests that approximately 16% can be attributed to the use of steel while 26% can be attributed to the use of clay, cement and lime (UK Government 2010). In recent decades we have seen improvement and optimisation of the manufacturing methods used for both steel and cement (Allwood and Cullen 2011). This improved material manufacturing has delivered much lower per tonne CO_2 emissions for steel and cement, but further improvements in manufacturing emissions for these materials will be increasingly difficult and expensive to achieve (Allwood and Cullen 2011, Eurofer 2015).

These projections and targets for reductions in GHG emissions by the UK construction industry must also be viewed against the background of growth in construction output which is projected to continue beyond 2022 (CITB 2018), the global construction market is expected to grow by at least 70% by 2025 (HM Government 2013). The demand for housing is expected to be a growth driver for UK construction well beyond 2022 (Jefferys et al. 2014). We are not planning to meet emission reduction targets by building at a slower rate, in fact we are planning to build ever faster.

Social Considerations

In addition to the legal requirements placed on the construction industry, the role of wider societal expectations around sustainability and environmental management must also be

acknowledged. Corporate Social Responsibility is becoming ever more significant amongst construction organisations, not least because their activities impact directly on society, the economy and the environment - the 'three pillars of CSR' (Murray and Dainty 2009, Chan and Cooper 2011, Upstill-Goddard et al. 2012). Organisations are therefore under pressure to demonstrate their commitments to reducing carbon within the built environment, and those who do not take such positive action will likely suffer within the commercial marketplace (Jones 2012).

Technical Considerations

It is clear then that the UK construction industry has a very significant role to play if the UK government is to achieve its 2050 GHG emissions reduction target, whilst meeting social expectations around sustainability, and still supporting increased construction output in the future.

Allwood and Cullen have carried out detailed studies of the dichotomy of the need to reduce GHG impact versus the increase in demand for materials (Allwood and Cullen 2011). Of particular interest here is their work which considers the sensitivity of GHG emissions to various steel usage parameters. While it is important to note that they did not limit their study to steel used in UK construction, it is notable that they found that the two most effective measures for reducing the CO_2 that is attributable to steel were i). demand reduction and ii). life extension (Allwood and Cullen 2011). It is clear, that when the principles of the circular economy (CE) are adopted within construction then we are able to achieve both demand reduction and life extension. We need to find innovative low energy techniques for re-use of existing components which do not rely on the high energy recycling route that we currently use in terms of steel or the wasteful downcycling route typically used for concrete.

The services provided by Portal Power (Eastern), based in Suffolk UK (Portal Power 2010), are a good example of a business built around CE principles. They provide the full suite of services that are required to disassemble, refurbish and re-erect industrial steel portalframe buildings. They also provide options for re-use of secondary steelwork and cladding elements. A refurbished steel portal frame building delivers in terms of demand reduction by re-using the hot rolled steel sections from a pre-used building in a re-constructed new-tothe-client building. It can also deliver in terms of life extension of the steel sections via inspection, refurbishment and re-application of corrosion protection. Allwood and Cullen's two most effective measures are both being applied.

SO WHAT ARE WE WAITING FOR?

The UK construction industry, both on the client side and the delivery side, is notoriously resistant to change. In his review of the UK construction labour model, Mark Farmer (2016) suggests a range of themes that contribute to the symptoms of failure within construction.

A number of these themes, for example structural fragmentation, lack of collaboration and low margins are pertinent to the discussion here as they directly contribute to innovation inertia from both sides of the industry.

One driver for the structural fragmentation that Farmer (2016) refers to is the traditional construction procurement route. This method of procurement encourages clear boundaries

between client, designer and constructor and places the constructor firmly in the project construction phase rather than the design phase. These boundaries and delineations are often cited as limitations which prevent full realisation of the benefits that, for example, Design for Manufacture and Assembly (DfMA) methodologies can deliver. Pre-cast concrete manufacturers will often cite "early engagement" of their services as critical to maximising the cost and programme benefits of pre-cast structural solutions (The Concrete Centre 2007). Traditional procurement and the competitive tendering process tend to inhibit this early engagement.

UK construction traditionally operates procurement processes in which there is poor collaboration and a somewhat adversarial relationship between client and constructor and often also between the designer and constructor. These relationships tend to be negatively nurtured by the competitive tendering process, yet we still want to maximise the benefits delivered by innovative products. There are clear parallels here with the separation of product innovation and process innovation discussed by Hullova et al (Hullova et al. 2016), their work recognises that changes in product often subsequently demand changes to process. In order to fully realise the potential of a new product we often need to modify the associated development and deployment processes.

In addition to the systemic issues that align to the Farmer Report, further barriers can also be identified in other areas, including technical, commercial and logistical. For example, construction technology often leads to the use of mixed materials within individual construction elements, which limits the options for re-use, for example the use of concrete on profiled metal decking, or the production of structural insulated panels etc. This limits the potential for certification of materials for re-use. Commercial barriers include the necessary consideration that property inflation dwarfs the value of the material in the fabric of an existing building, which disincentivises investment in any long-term approach to reuse. Logistically, a CE can necessitate the need for appropriate storage of materials during the period of time between dis-assembly and reconstruction, and so can limit the appetite for manufacturers to adopt this approach from practical perspectives.

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

With reference to Farmer's "chemical chain reaction" analogy, it is suggested that the Circular Economy concept could act as the catalyst that is needed to speed up the transformational changes within UK construction that are required to meet GHG emission reductions as well as to improve efficiency in general, and that such benefits will outweigh, overcome or eliminate any barriers going forwards.

In order to mobilise this in practice, empirical work is needed to overcome these barriers, and demonstrate the benefits a CE approach can bring to the built environment. Exemplar case studies are proposed, drawing on projects that have used previously developed sites, and which involved the demolition or partial demolition of any existing buildings prior to constructing the new project. Retrospective analysis can be used to explore to what extent CE principles could have been employed on such projects, and the GHG emission benefits this could have brought. From this retrospective analysis, the common features and characteristics in the projects in

relation to the potential use of CE can be determined, and therefore the bigger/easier GHG 'wins' that can be taken forward to future projects can be identified.

The authors have presented this work with the intention of stimulating discussion, and welcome feedback, comment and critique from our SEEDS colleagues as to the role CE approaches can play in the built environment of the future.

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EXPLORATORY STUDY INTO SUSTAINABILITY EXPERTISE IN THE IRISH ARCHITECTURE, ENGINEERING AND CONSTRUCTION (AEC) SECTOR.

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Keywords: Sustainability expertise, sustainable practice, Irish construction

ABSTRACT

The Architecture, Engineering and Construction (AEC) sector is a rich environment, involving the use of expertise at various levels with much intensity and in unique situations. In the attainment of sustainable construction, construction sustainability performance is indispensable. The participants implementing sustainable construction practices are key to a sustainable construction sector. This study seeks to understand the level of sustainability expertise in the Irish AEC sector which is part of an ongoing research at the Dublin Institute of Technology, within the School of Surveying and Construction Management. The early explorative phase of this research involves getting a depth of understanding as to the level of sustainability expertise in the Irish AEC sector. The study adopts a bibliometric review as its method to explore how the sector has begun to change its practice around addressing sustainability expertise and performance. The outcome of this review confirms that a number of gaps do exist in the Irish AEC sector with regard to sustainability expertise in skills shortage and the need for skills development.

INTRODUCTION

The issue of sustainability in the Architecture, Engineering and Construction (AEC) sector is of prime concern these days as clients are requesting for more sustainable projects. Since the introduction of the philosophy of sustainable development by the Bruntland report in 1987, many industrial sectors have since then being taking steps to achieving sustainable development. Sustainable construction is a way for the AEC sector to contribute to the effort to achieve sustainable development. Sustainable development as defined by the Bruntland report (1987) is a concept that meets the requirements of existing generations without compromising the ability of upcoming generations to meet their own requirements.

In achieving sustainable construction, the participants implementing sustainable construction practices play a great role. According to Addis et al. (2016), excellent performance is underpinned by expertise and is central to achieving sustainable construction. Expertise collectively refers to the individuals together with their attributes and skills (Addis et al., 2016; Brand and Karvonen, 2007). This paper is an attempt to assess sustainability expertise in the Irish AEC sector as it moves towards the attainment of a more sustainable construction sector.

IRISH AEC SECTOR

The AEC sector in Ireland has emerged from a deep recession and is currently at a transitional stage (see fig. 1). The industry entered a deep recession but has sustained continual growth since the year 2012. Following years of decline in output from the years 2008 to 2012, the Irish economy has shown continual growth since 2013 and continues to grow (SCSI, 2016). The sector accounted for 6.6% of Gross National Product (GNP) in the year 2013 and since then has shown progressive growth due to quality economic decisions since 2008, as can be seen in table 1. The sector is forecasted to reach a value of 20 billion euros, which will approximately account for 7.6% of GNP in this year 2018 (See table 1). These proportions however are still below the 10% to 12% ratio considered a sustainable level by European standards (Linesight, 2018).

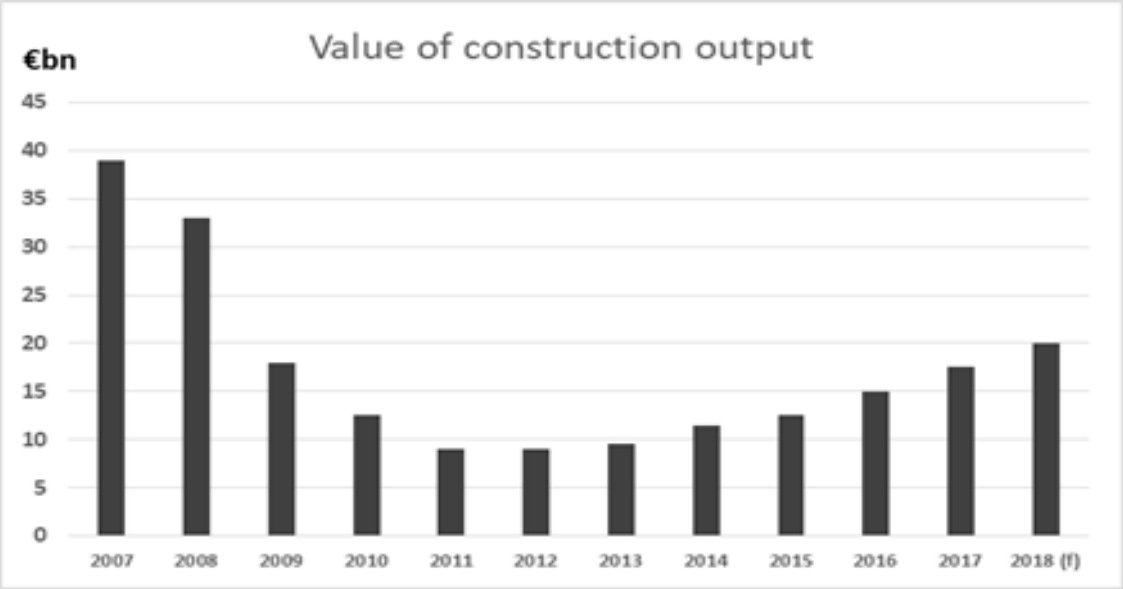


Figure 1. Value of Irish Construction Output 2007-2018
Source: Linesight, 2018

Table 1: Irish Construction Output 2012-2018

	2012	2013	2014	2015	2016	2017	2018 (f)
Value of output at current prices (€m)	9,395	9,723	11,147	12,650	14,935	17,500	20,100
Construction output as % of GNP	7.1%	6.6%	6.8%	6.2%	6.6%	7.0%	7.6%

Source: Linesight, 2018
Forcasted (f)

The renewed focus on recovery and growth of the Irish economy after quite a lengthy and deep recession is well appreciated (SCSI, 2016). Prospects for the construction sector appear brighter now than they have been in almost a decade as forecast by the sector and evidenced by the growth in construction production (Linesight, 2018). This nonetheless, the construction sector continues to face severe challenges and not the least of which is ensuring that it has the capacity to meet the recovery in demand which is expected to materialise over the coming years. A report by the Construction Industry Federation (CIF) (2016) of Ireland on 'construction skills and prospects' recognizes skills shortage as a significant challenge facing the Irish AEC sector. The severity of the construction recession has seen a major decline in the numbers working in the sector. If the required supply levels are to be delivered, the industry will need to ensure it has sufficient craftspersons and skilled workers. A skills shortage could threaten to derail the positive outlook for the AEC sector. An enhancement of the skills capacity in the industry is also required to ensure the industry can deliver the demands placed on it. According to a report (Building for Growth) from SCSI (2016), Ireland needs a construction sector which can support the ongoing recovery and growth of its economy. It further stated that a sustainable construction sector is a key element of any properly functioning economy. For Ireland to meet its output projections, the capacity of the construction sector will need to be boosted to be strong and more sustainable to help the economy as it grows into the future. Speedy measures should be implemented to ensure that the sector can meet the anticipated growth and reach sustainable levels for the benefit of the overall economy. This has inspired the study into sustainability expertise in the Irish AEC sector.

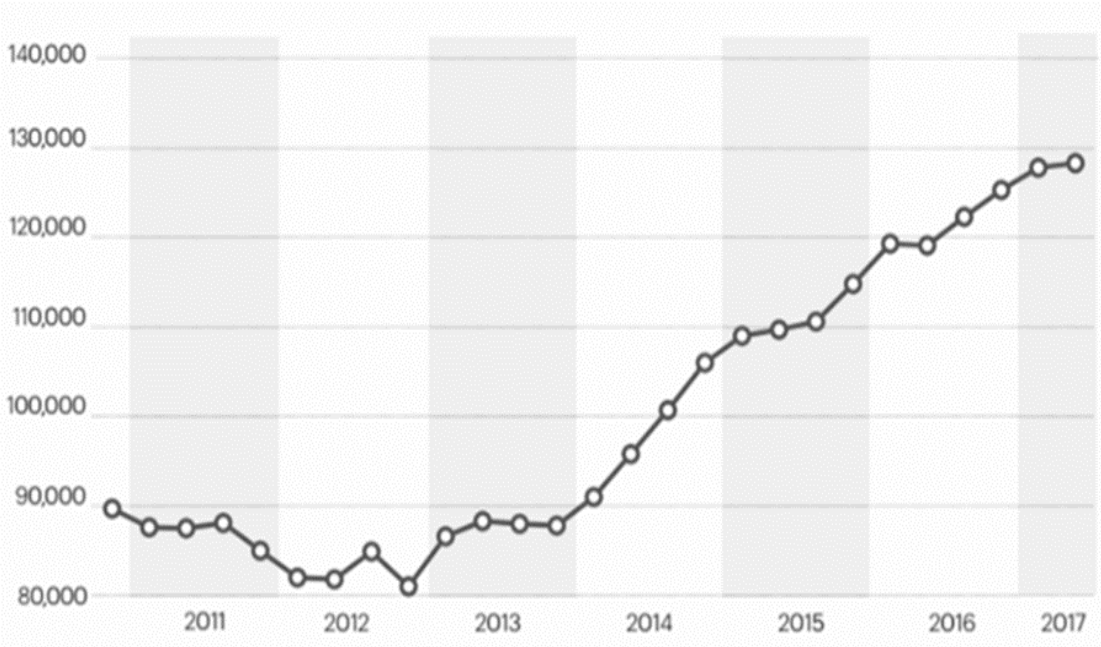


Figure 2. Employment in Irish Construction 2011-2017
Source: Linesight, 2018

SUSTAINABLE DEVELOPMENT AND SUSTAINABILITY EXPERTISE

Sustainability can generally be defined as the ability to be maintained over a long term (Anon., 2013). The concept of sustainability as defined by the Bruntland report (1987) is 'forms of progress that meet the needs of the present without compromising the ability of future generations to meet their needs'. It further defined sustainable development as 'development that meets the needs of the current generation without undermining the ability of future generations to meet their own needs.' The concept of sustainability is of prime concern in the AEC sector as the sector has been accused of causing problems ranging from excessive consumption of global resources to the pollution of its surrounding environment. Appropriate strategies, actions and practices are needed to help create a sustainable AEC sector (Scott and Bhattacharjee, 2017). The study of sustainability expertise in the Irish AEC sector is an attempt to help in this regard.

The ever evolving nature of technology coupled with the increasing reliance of society on technology create the need for expertise development and management. In this modern technological world of rapid change and unpredictable unknowns, sustainability and knowledge are key skills of the AEC sector in keeping pace (Scott and Bhattacharjee, 2017). Technology plays a dominant role in society and more sophisticated technologies require individuals or consumers who understand the underlying scientific and technical principles. Hence the need for expertise development and management to keep pace (Kanjanabootra, 2017; Brand and Karvonen, 2007). This suggests that efforts to create a more sustainable development projects require participants or technical experts who understand the underlying principles of adopted technologies and practices.

Expertise as defined by Ericsson (2014) refers to 'knowledge and skills that collectively represent the mastery of a particular subject, achieved through instruction and experience'. Sage (2016) defined expertise in the field of construction as the acquisition of knowledge and skills related to a technical process, health and safety codes, organizational routines or even cultural norms. Addis et al. (2016) also explained expertise as individuals together with their skills and attributes. Expertise spans reason, intuition, knowledge, learning and action as well as being an individual and a collective attribute. For the purpose of this study, expertise is defined as individuals together with their act of acquiring knowledge and skills towards the mastery of a particular subject.

Expertise Development

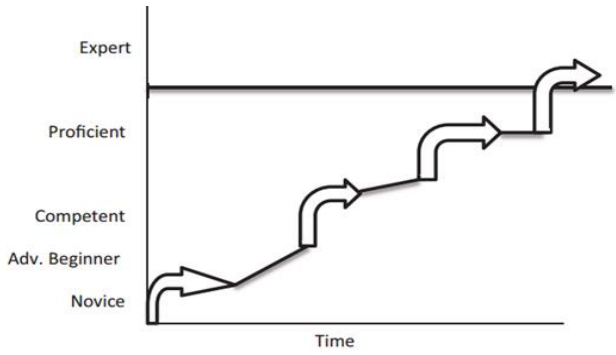
The AEC sector is a rich environment, involving the use of expertise at various levels in much intense and unique situations. The problems with the sector do not hence lie with the practices themselves (Boyd and Addis, 2011). According to Newton (2016), the concept of expertise plays a central role in the field of construction, be it in professional practice, research or education. This is reinforced by Addis et al. (2016) stating that excellent performance is underpinned by expertise and is central to achieving sustainable construction. The development and management of sustainability expertise is indispensable in meeting the demands of sustainable development projects. This includes an assessment of technical experts and other practitioners such as engineers, architects, contractors and other

professionals who are involved in sustainable development projects. Sustainable development calls for people skilled at understanding and employing sustainability principles and thus, efforts to create more sustainable development require an examination of the opportunities and dangers of involving these technical experts (Brand and Karvonen, 2007).

The development of expertise usually starts in the form of some training which could be either formal or informal. Formal training could be in the form of a university or vocational institution and informal training could be in the form of apprenticeship (Kanjanabootra, S., 2017). Dreyfus and Dreyfus (1986) proposed a model for expertise development which described it as a journey from a 'novice' to an 'expert'. The model described expertise as a function of experience and time where an individual enters a field as a novice and with experience and over a period of time becomes an advanced beginner, competent, proficient and ultimately an expert. Boyd and Addis (2011) endorse how relevant the Dreyfus model is in skills acquisition in construction. Their study confirmed that, rules may be needed when learning, but one must eventually set them aside if one is to become an expert. That is to become as expert, one has to switch from detached rules to a more involved and situation specific way of coping. The Dreyfus model has been summarized below:

1. **Novice**: adheres to rules strictly and without discretionary judgement.
2. **Advanced beginner**: has limited perception of situations though areas of knowledge and tasks have increased.
3. **Competent**: begins to cope with complex situation in a way such that actions involve long term goals.
4. **Proficient**: has holistic view of situations and can identify what is most important in a given situation.
5. **Expert**: has an intuitive appreciation of situations and with very little need for rules.

This study has been expounded by Kuhlmann and Ardichvili (2015) that professionals in a discipline will develop expertise through years of engaging in a high-value, non-routine work. The results of their study is shown in figure 3. The findings of Kuhlmann and Ardichvili (2015) study agree with Kanjanabootra and Corbitt (2016) in that knowledge and expertise accumulate through practice or experience. Kanjanabootra and Corbitt (2016) show in their study that learning and expertise development in construction professionals emerges incrementally and contextually from their peers and within cultural/social practices.



This diagram illustrates that expertise development is achieved through progressive problem solving comprising of series of discrete learning events (arrows) linked by routine problems (lines)

Figure 3. Expertise development levels
Source: (Kuhlmann and Ardichvili, 2015)

An understanding of expertise development is essential as this will enable organisations know what level their professionals are and can better develop their appropriate expertise (Scott and Kanjanabootra, 2018). Scott and Kanjanabootra (2018) further stated that mostly when construction professional are faced with difficult projects early in their career, they face series of steep learning curves and this challenges their competency as expertise development emerges incrementally and contextually. An understanding of this therefore will enable organisations provide the necessary training programs on which professionals can better develop their appropriate expertise.

RESEARCH METHOD

This research gains high motivation from the approach to study and gain a better understanding of the AEC sector expectations about essential sustainability knowledge and expertise in an ever changing and fast paced industry. The methodology applied was determined on the basis of relevance to the focus of this stage of the research enquiry but also on the basis of pragmatic positioning. This was the case as a different methodological stance would not have allowed the research to be completed within the constraints applicable. Creswell (2009) has stated that research methodology is the systemic approach that a research project adopts to accomplish the research's aim and with that in mind an explorative interpretivist position has been adopted. In relation to the purpose of the research: it is concluded that the theoretical argument developed for the enquiry has the potential, by using an explorative perspective, to reveal new insights and a better understanding of the awareness of sustainability and whether there is some alignment of those positions.

The overall research project will involve a mixed methodological approach, which for the purposes of this paper is beyond the scope of this paper as the early phase of the research has just been completed. What is present in the paper, is a justification of the approach taken for the bibliometric review. Traditional research design strategies usually rely on a literature review leading on to the formation of a hypothesis which can be put to test by experimentation in the real world. This is the goal of this stage of the research.

FINDINGS

This paper has shown the relevance of expertise in the AEC sector in fostering sustainable construction and more especially, in the Irish AEC sector. The paper is mainly a synthesis of available literature detailing the essence and need for an assessment of sustainability expertise in the Irish AEC sector. The findings from literature has been shown in table 2 below. The findings from the review clearly show that expertise development is vital to achieving a sustainable construction.

Table 2: Sustainability expertise indicators towards a sustainable construction (Ireland's AEC sector)

Issues/themes	Indicators	Source
Relevance of expertise in the AEC sector	The AEC sector is a rich environment, involving the use of expertise at various levels in much intense and unique situations. The problems with the sector do not hence lie with the practices themselves but very much with the people	(Newton, 2016; Boyd and Addis, 2011)
	'Excellent performance is underpinned by expertise so the latter has a central role in the undertaking and explanation of successful construction practice.'	(Addis et al., 2016)
	The ever evolving nature of technology coupled with the increasing reliance of society on technology create the need for expertise development and management. Sustainability and knowledge are key skills of the AEC sector in keeping pace	(Kanjanabootra, 2017; Scott and Bhattacharjee, 2017; Brand and Karvonen, 2007).
Irish AEC sector and sustainability	The AEC sector in Ireland entered a deep recession but has sustained continual growth since the year 2012. Despite the continual growth percentages of 6.6% to 7.0% of GNP, these proportions are still below the 10% to 12% ratio considered a sustainable level by European standards.	(Linesight, 2018)
	The severity of the construction recession saw a major decline in the numbers working in the sector and since then, skills shortage is seen as a major challenge facing the Irish AEC sector. Skills shortage could threaten to derail the positive outlook for the Irish AEC sector. An enhancement of the skills capacity in the industry is also required to ensure the industry can deliver the demands placed on it.	Construction Industry Federation (CIF) (2016) of Ireland
	Ireland needs a more sustainable sector which can support the ongoing recovery and growth of its economy. Speedy measures should be implemented to boost the sector's capacity as it grows into the future and reach the 10% to 12% ratio considered a sustainable level by European standards.	Society of Chartered Surveyors Ireland (SCSI) (2016)
Expertise Development	The development and management of expertise such as engineers, architects, contractors and other professionals in the AEC sector is indispensable in meeting the demands of sustainable development projects. Sustainable construction calls for people skilled at understanding and employing sustainability principles	(Brand and Karvonen, 2007).

CONCLUSION

The early literature review illustrates the importance of questioning the definition of sustainability expertise discourse. Whether the problem is defined as one of bureaucracy or inadequate social mix, it is important to recognise that the decision to acknowledge that there exists a position that expertise in the AEC sector is a problem will be ideologically loaded. To

make the claim that sustainability expertise is lacking among AEC professionals as an important weakness is an outcome of the literature review. What discourse to use to delve further to unpack the different components of what is regarded as a distinct contribution to knowledge around sustainable expertise needs some direct consideration and will form the next phase of this research.

This study, so far, has confirmed gaps in the Irish AEC sector regarding sustainability expertise and the need for the sector's capacity to be boosted to be more sustainable. Skills shortage and development has been shown to be a major challenge facing Ireland's AEC sector. An empirical assessment of the level of sustainability expertise in the sector will therefore contribute greatly in helping in this regard which will be the follow on stage of this study. By clearly showing the state of the AEC sector in Ireland, this paper hence confirms the need for an empirical assessment of the sustainability expertise of the sector. This will as well boost the sector's capacity to increase its contribution to Gross National Product (GNP) to reach a sustainable level. European sustainability standards considers a sector's contribution to Gross National Product (GNP) as a sustainable level when it is above 10%.

This paper has shown that excellent performance is underpinned by expertise and how relevant the level of expertise development is in the AEC sector. An understanding of the levels of expertise development will enable organisations know what level their personnel are in their expertise can better develop their appropriate expertise. The follow on stage will be to collect empirical data from Ireland's AEC sector regarding the level of sustainability expertise and how this expertise is being used to advance the industry.

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$C0_2$ and Embodied Energy

POTENTIAL CARBON EMISSIONS REDUCTION IN GENERAL AUSTRALIAN CONSTRUCTION SYSTEMS THROUGH THE USE OF BIOCLIMATIC DESIGN PRINCIPLES

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Keywords: Construction Materials, Carbon Emission, Sustainable Construction, Bioclimatic Design Principles (BDP).

Abstract

This paper outlines the results of applying a developed research model tool based on bioclimatic design principles to building materials, elements and construction processes within general Australian floor, wall and roof construction systems. The aim of the research was to identify potential reductions in construction carbon emission that might be achieved during the construction process in the general Australian (floor, wall and roof) construction systems. It was found that, as compared to standard building practice and application of the Australian Green Star environmental tool, the bioclimatic research model consistently produced potentially higher reductions in construction carbon emissions for all building materials and elements considered – up to 93 percent for roof construction systems. The construction sector produces around 11 percent of Australian greenhouse gas emissions, and the Australian Federal Government has set a target emission reduction of 26 to 28 percent by 2030 to achieve the 2015 Paris agreement. Given this, consideration of bioclimatic design principles in building design and construction should be an important part of the process to reduce Australian construction carbon emissions to achieve the Paris agreement goals.

INTRODUCTION

The United Nations Environment Program reports in its Sustainable Buildings and Climate Initiative that the building sector is responsible for 40 percent of global energy use. This sector also generates more than one third of global greenhouse gas emissions, and is the largest emission source in most countries around the world (Sustainable Buildings & Climate Initiative (UNEP SBCI), 2009). In Australia, the building sector is reported to be one of the largest contributors to Australian greenhouse gas (GHG) emissions, and thus has the greatest potential for a significant reduction in GHG emissions as compared to other major emitting sectors (Green Building Council of Australia (GBCA), 2008). In fact, it is estimated that up to 60 Mt of carbon-reduction opportunities can be achieved in the Australian building sector by 2030 (McKinsey, 2008). The scale for emission reduction in building construction is significant. The building sector has the largest potential for delivering long-term, significant and cost-effective reductions in greenhouse gas emissions (Sustainable Buildings & Climate Initiative (UNEP SBCI), 2009). For example, the UK Indemand research Centre believes that the construction emissions of commercial buildings in the United Kingdom can be cut by 80 percent, the target set by the 2008 Climate Change Act (UK Indemand, 2014). A report by the World Business Council for Sustainable Development (WBCSD) believes that an investment of

US$150 billion annually would cut the carbon footprint of buildings by 40 percent (The World Business Council for Sustainable Development (WBCSD), 2014. With proven and commercially available technologies, the energy consumption in both new and existing buildings can thus be cut by an estimated 40 to 80 percent during the building life-span. This potential for greenhouse gas emission reduction from buildings is common to both developed and developing countries (Sustainable Buildings & Climate Initiative (UNEP SBCI), 2009).
This paper outlines the results of applying a research model to building materials within general Australian floor, wall and roof construction systems – the aim was to identify potential reductions in carbon emission that might be achieved during the construction process. The criteria within the research model are based on bioclimatic design principles (BDPs), and the model was developed as part of a doctoral thesis that considered the application of BDPs as a method to reduce the carbon emissions of construction. At the first stage, it has been used with the case studies and this time was used within general Australian construction systems.

Carbon emissions and embodied energy of buildings

Embodied energy represents the energy consumed by all processes associated with the production of a building, from the mining and processing of natural resources, to manufacturing, transport and product delivery (Milne, 2014). Embodied energy can be broken down into direct and indirect energies. Direct embodied energy relates to the energy involved in transportation of construction materials, and then assembling those materials on site. Indirect embodied energy relates to the energy put 'into' the component itself, in terms of extracting it from the ground, then the energy consumed in its processing and manufacturing together with generated carbon emissions (Bull, 2012). It was thought until recently that the embodied energy content of a building was small compared to the energy used in operating the building over its life. Most effort, therefore, was put into reducing operating energy by improving the energy efficiency of the building envelope. However, this is not always the case. For example, research on office construction shows that embodied energy can approach 37 years of operational energy (Ding, 2007). Research by the Australian Commonwealth Scientific and Industrial Research Organization, (CSIRO) has also found that the average house contains about 1,000GJ of energy embodied in the materials used in its construction. This is equivalent to about 15 years of normal operational energy use. For a house that lasts 100 years, this is over 10 percent of the energy used in its life (Milne, 2014).

Given the above, it can be seen that embodied energy is the equivalent of many years of operational energy, and thus attention must be paid to reducing the embodied energy of materials used in construction – including the energy consumed in mining and processing of natural resources; in the manufacture, transport and product delivery; and then in the construction process itself. It is the embodied energy of the materials used in general Australian construction systems and their equivalent construction carbon emissions which provide the basis for this study. The embodied energies of Australian building materials have been identified by Lawson (1996; 2006), and they are converted to their equivalent carbon emissions based on the Australian Government's accepted global average of 1 MJ = 0.098 $kgCO_2eq$ (CSIRO, 2014).

Bioclimatic design principles

In the early 1960s, bioclimatic design principles were identified and defined by the twin Olgyay brothers as those principles that bring together the disciplines of human physiology, climatology and building physics (Altomonte, 2008), (Hyde, 2008). Victor Olgyay (1910–1970) is today the better known of these brothers, particularly as the author of *Design with climate*: *Bioclimatic approach to architectural regionalism* (Olgyay, 1963), a book often referenced in the environmental building design field (Leather, 2014). There are two main aims in bioclimatic construction – first, to ensure that the constructed building can function satisfactorily within current and future climatic conditions; and, second, that the environmental impact of existing buildings is reduced through reduction in their energy use and greenhouse gas emissions (Clarke, 2008). Research has found that appropriate bioclimatic design can reduce energy consumption in a building as compared to conventional building design (Jong, 1998). Use of these principles has thus been integrated into building design in the context of regionalism in architecture, and they are increasingly regarded as a cornerstone for achieving more sustainable buildings (Hyde, 2008), (Hyde, 2009).

The following is a summary of the general bioclimatic principles that underpin the model proposed in this paper. They focus on the use of sustainable materials to minimize carbon equivalent emissions.

- Minimise energy consumption in mining, processing, equipment, pre-assembly and assembly in manufacturing. Criteria measured are reduced energy use in mining, processing, and construction materials.
- Minimise transportation at all stages of the building process. Criteria measured are reduced energy due to preassembly and reduced materials transportation.
- Minimise use of resources, achieving waste reduction by facilitating reuse and recycling. Criteria measured are reduced energy by recycling and reuse of building materials and building elements.
- Maximise use of renewable energy. Criteria measured are replaced and saved energy in mining and construction (preassembly, professional worker transportation, site processing, materials transportation).

Research rationale

1. The building sector has a significant potential for delivering long-term, significant and cost-effective reductions in greenhouse gas emissions. This potential is common to developed and developing countries (Sustainable Buildings & Climate Initiative (UNEP SBCI), 2009). The goal is to reduce the total quantity of greenhouse gases getting into the atmosphere as quickly as possible, so reducing carbon emissions of building materials has an important role.

2. Until recently, it was generally considered that carbon emission from building construction was small relative to that from operations over the building's lifetime. Accordingly, reducing the energy and carbon footprint of the building sector has focused mostly on reducing operating energy by improving the energy efficiency of the building envelope. However, carbon emission from construction processes can be equivalent to as much as 37 years of operational carbon (Ecospecifier, 2015), (Canadian Architects, 2015).

3. There are some recent successful achievements in this field of reduced emissions including the London Olympic Buildings in 2012 (Craven 2012; Learning Legacy 2014); reconstruction following Hurricane Sandy in the USA (Inhabitat, 2014); and LEED attention and certification for reusing construction materials (LEED, 2014). In these cases, considerable and substantial reduction in carbon emission was achieved through use of bioclimatic principles during building construction processes. Additionally, the UK government has funded a core team of sixteen postdoctoral researchers within the four universities of the UK Indemand center. They will examine all aspects of implementing material efficiency in the UK; they have also recently announced that the construction embodied emissions of buildings in the UK can be cut by 80 per cent within the next three decades (UK Indemand, 2014).

4. Construction waste constitutes about 40 per cent of the total solid waste in the USA (Green Vally, 2013); and Australians produce more than one-and-a-half tonnes of waste per person per year, with 40 per cent of Australia's waste resulting from construction and demolition activities (Hawkesbury City Council, 2014).
Reuse and recycling of construction materials is now a generally accepted practice (LEED, BREEAM, and Green Star), legislated for, and being used is environmental assessment processes. These grant considerable credits for using, reusing, recycling, upcycling, waste management, and using regional materials. Cascione, 2010).

RESEARCH OBJECTIVES AND METHODOLOGY

The aim of this research is to identify potential carbon emission reductions that could be achieved during the pre-construction and construction stages of the building lifecycle (i.e. the first three stages of the lifecycle: extraction, production and construction). The focus is on three areas – first, in reducing carbon emission from energy consumed during ***extraction and production*** of building materials and elements; second, during ***implementation***; and finally, during ***transportation.*** At this stage, the research model and calculations have been applied only to the major building elements (floor, wall and roof) of general Australian construction systems as identified in Lawson (1996; 2006), but they can be applied to any project from any classification (residential, public, or commercial). The measurable bioclimatic criteria applied in the research model are summarized in Table 1.

Typical embodied energy units are measured using MJ/kg (megajoules of energy needed to make one kilogram of product), and these must be converted to equivalent kilogram carbon emissions. However, such conversion is not straightforward because different types of energy (oil, wind, solar, etc.) emit different amounts of carbon dioxide, thus the actual amount of carbon dioxide emitted when a product is made will depend on the type of energy used in the manufacturing process. To facilitate this conversion, the Australian Government's accepted standard (1 MJ = 0.098 kgCO_2) has been used to convert embodied energy to equivalent carbon emissions (CSIRO, 2014).[1]

[1] Presentation of the full data sets and calculations on which the bar graphs and tables in this paper are based is not possible in this article due to space limitations. However, these can be supplied to interested persons on email request to author 1 of this article, Sattar Sattary – sattar.sattary@usq.edu.au

Table 1: Bioclimatic criteria applied in the research model

Bioclimatic principles applied in this research	Application
Reusing recycled aggregates in materials production instead of extracting new aggregate from mining	This includes replacing concrete with 80 percent recycled aggregate, and 100 percent for non-structural purposes (Uche, 2008); and brick with 67 percent recycled aggregate (Brick Development Association, 2014),(Tyrell, 2014).
Using steel from recycled content instead of steel from mining of raw materials	This includes the reuse of steel mesh, edge beams, and steel sheets, aiming towards 100 percent replacement from recycled content (SteelConstruction.info, 2014),(Greenspec, 2015).
Reusing recycled construction materials and elements	This includes reusing post-consumer recycled timber and/or certified timber from the Forest Stewardship Council (FSC) (Green Building Council of Australia (GBCA), 2008), (Design Coalition, 2013); use of insulation from recycled materials (Greenspec, 2015); use of recycled concrete roof tiles (LEED Leadership in Energy and Environmental Design, 2014); and reuse of structural elements (Karven, 2012).
Replacing Portland cement with geopolymer based cement	This includes full replacement of Portland cement with cement substitute – 80 percent for concrete for structural purposes, and 100 percent for non-structural purposes (McLellan, 2011), (Nath, 2014).
Using types of transportation that generate less carbon emissions	This refers to use of sustainable modes of transportation such as ship and rail instead of trucks/road transportation, (Learning Legacy, 2012).

OUTCOMES OF THIS RESEARCH

This section describes the potential construction carbon emission reductions that can be achieved from application of the bioclimatic criteria in the research model to the floor, wall and roof materials of general Australian construction systems. For each of these construction systems, there are two items presented – first, a bar graph comparing the carbon emissions generated in normal construction practice with those potentially achieved after application of the Green Star environmental assessment tool, and the research model; second, there is a table comparing the potential carbon emission reductions that can be achieved through application of the Green Star tool and the research model.

The followings are the "carbon emissions the Generated in general Australian construction systems" and "carbon emissions Reductions in the Generated in general Australian construction systems".

General Australian Floor construction systems

In respect to general Australian floor construction systems, the bar graph (Figure 1) of carbon emissions generated indicates that, following application of the research model to the floor

systems, generated carbon emissions are consistently lower in comparison to standard building practice or use of the Green Star tool.

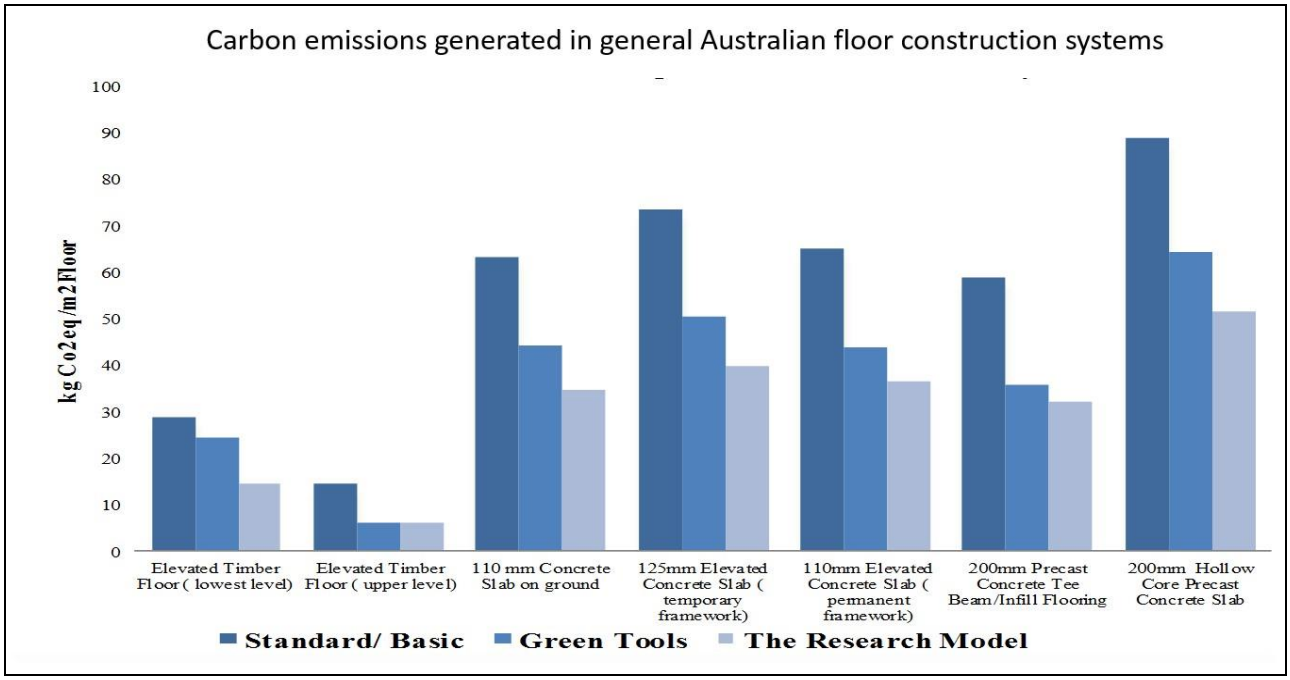

Figure 1: Bar graph of carbon emissions generated in general Australian **Floor** construction systems – comparing levels generated in standard/basic construction practice with those where the Green Star tool and the bioclimatic criteria of the Research Model have been applied.
Standard/Basic: Based on bioclimatic conditions identified in Table 1, embodied energies of the building materials and Australian construction systems (floors, Walls and roofs) have been calculated based on Lawson's book "*Building materials, energy and the environment: Towards ecologically sustainable development*" (Lawson, 1996). They are converted to carbon emissions based on Australian government's global average of 1 MJ = 0.098 $kgCO^2$ (CSIRO, 2014).
Green Tool: Based on bioclimatic conditions identified in Table 1, the potential construction carbon emission reductions through credits from green tools were calculated the using green tools technical manual (Green building Council of Australia, 2008).
Research Model: Based on bioclimatic conditions identified in table 1; the construction carbon emission reductions were calculated and compared with Standard/Basic construction carbon emissions.

This trend is also seen when percentage carbon reductions are considered for floor systems as in Table 2. The potential carbon emission reductions achieved by application of the Green Star tool ranged from 15.56 to 57.55 percent. In comparison, the potential carbon emission reductions achieved by application of the bioclimatic criteria of the research tool were higher for all floor systems, ranging from 33.37 to 57.55 percent. Overall, the research model criteria clearly show the greater potential reduction in carbon emissions for Australian floor construction systems.

Table 2: Potential carbon emission **Reductions** in general Australian **Floor** construction systems

General Australian **Floor** construction systems	**Green tool**	**Research model**
	Carbon Emissions Kg/m^2	Carbon Emissions Kg/m^2
a. Elevated Timber Floor (lowest level)	15.56 %	50.02 %
b. Elevated Timber Floor (upper level)	57.55 %	57.55 %
c. 110 mm Concrete Slab on ground	30.18 %	45.17 %
d.125mm Elevated Concrete Slab (temporary framework)	31.30 %	45.96 %
e. 110mm Elevated Concrete Slab (permanent framework)	32.80 %	43.95 %
f. 200mm Precast Concrete Tee Beam/Infill flooring	39.61 %	45.43 %

g. 200mm Hollow Core Precast Concrete flooring	27.42 %	33.37 %

Source: Derived from data set produced for doctoral research (Sattary 2017) (Supporting data and calculations available on request from author).

General Australian Wall construction systems

In respect to general Australian wall construction systems, the bar graph (Figure 2) of carbon emissions generated indicates again that application of the research model consistently produces the lowest emissions in comparison to standard building practice or use of the Green Star tool. This is confirmed when percentage emission reductions are considered as shown in Table 3, where Green Star emission reductions range from 3.52 to 76.23 percent, in comparison to application of the research model where reductions range from 16.84 to 93.54 percent, and potential carbon emission reductions are higher for all Australian wall construction systems from use of the research model.

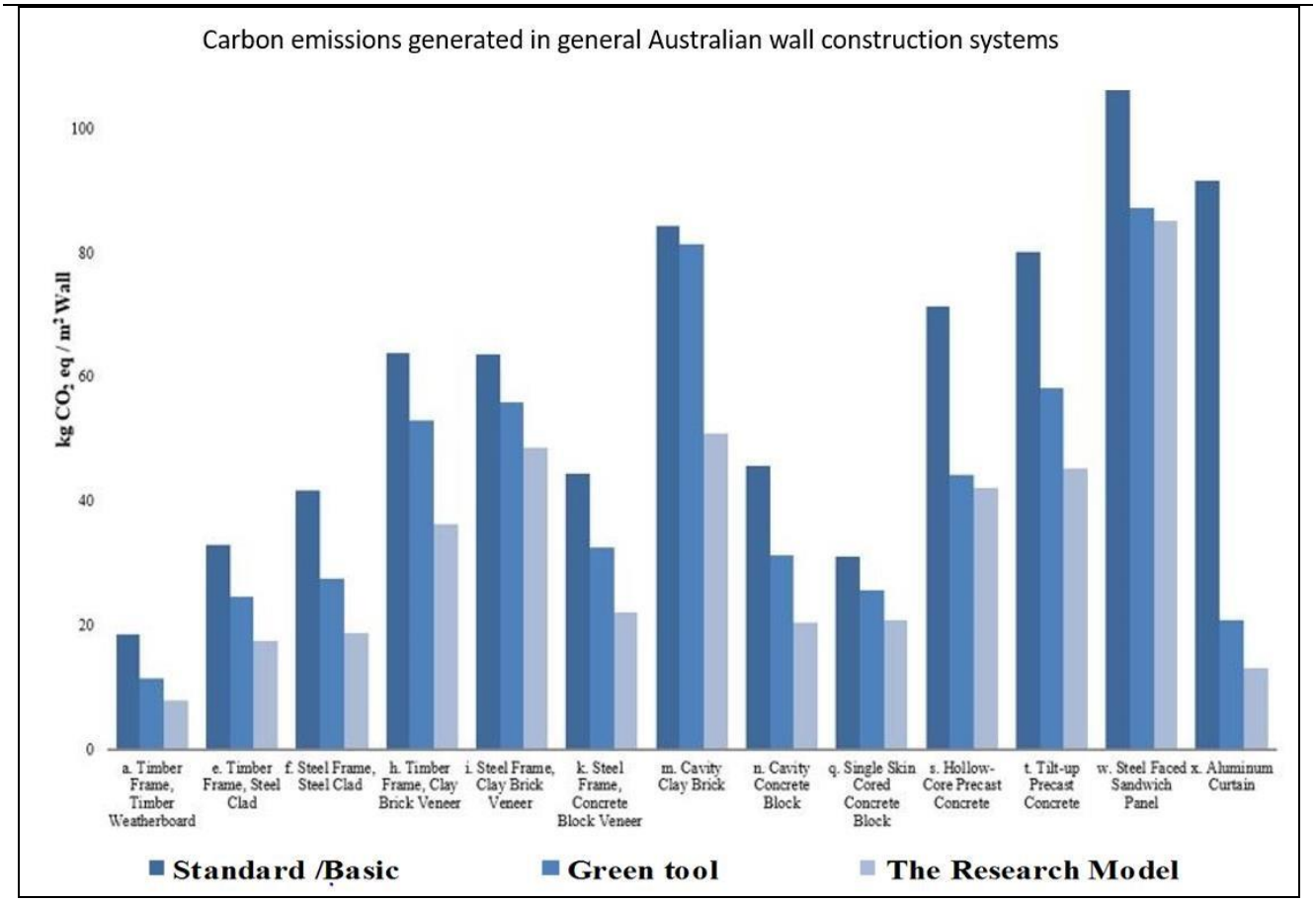

Figure 2: Bar graph of carbon emissions generated in general Australian **Wall** construction systems – comparing levels generated in standard/basic construction practice with those where the Green Star tool and the bioclimatic criteria of the Research Model have been applied.

Table 3: Potential carbon emission **reductions** in general Australian **Wall** construction systems

General Australian **Wall** construction systems	**Green tool**	**Research model**
	Carbon Emissions Kg/m^2	Carbon Emissions Kg/m^2
a. Timber Frame, Single Skin Timber Wall	26.72 %	27.39 %

b. Timber Frame, Timber Weatherboard Wall	37.79 %	56.92 %
c. Timber Frame, Reconstituted Timber Weatherboard Wall	76.32 %	84.88 %
d. Timber Frame, Fiber Cement Weatherboard Wall	21.02 %	41.77 %
e. Timber Frame, Steel Clad Wall	34.06 %	46.82 %
f. Steel Frame, Steel Clad Wall	33.75 %	55.18 %
g. Timber Frame, Aluminium Weatherboard Wall	66.02 %	76.39 %
h. Timber Frame, Clay Brick Veneer Wall	3.52 %	34.15 %
i. Steel Frame, Clay Brick Veneer Wall	12.11 %	23.84 %
j. Timber Frame, Concrete Block Veneer Wall	21.24 %	36.55 %
k. Steel Frame, Concrete Block Veneer Wall	26.80 %	50.45 %
l. Steel Frame, timber weatherboard Wall	56.64 %	93.54 %
m. Cavity Clay Brick Wall	3.38 %	39.54 %
n. Cavity Concrete Block Wall	31.23 %	55.09 %
o. Single Skin Stabilised Rammed Earth Wall	23.64 %	67.58 %
p. Single Skin Autoclaved Aerated Concrete (AAC) Block wall	9.21 %	16.84 %
q. Single Skin Cored Concrete Block Wall	17.76 %	32.71 %
r. Steel Frame, Compressed Fibre Cement Clad Wall	41.22 %	73.33 %
s. Hollow-Core Precast Concrete Wall	25.73 %	40.98 %
t. Tilt-up Precast Concrete Wall	27.38 %	43.63 %
u. Porcelain-Enamelled Steel Curtain Wall	55.59 %	60.74 %
v. Glass Curtain Wall	58.62 %	63.90 %
w. Steel Faced Sandwich Panel Wall	18.12 %	20.07 %
x. Aluminium Curtain Wall	72.23 %	85.82 %

Source: Derived from data set produced for doctoral research (Sattary 2017) (Supporting data and calculations available on request from author).

General Australian Roof construction systems

In the case of general Australian roof construction systems, the bar graph (Figure 3) confirms that carbon emissions generated after application of the research model are consistently lower than in standard building practice or with application of the Green Star tool. This trend is confirmed in reference to the percentage emission reductions in Table 4. Reductions for use of the Green Star tool range from 11.69 to 36.97 percent, in comparison to the research model where the range is from 15.69 to 57.40 percent, and again potential emission reductions are higher for all Australian roof construction systems through use of the research model.

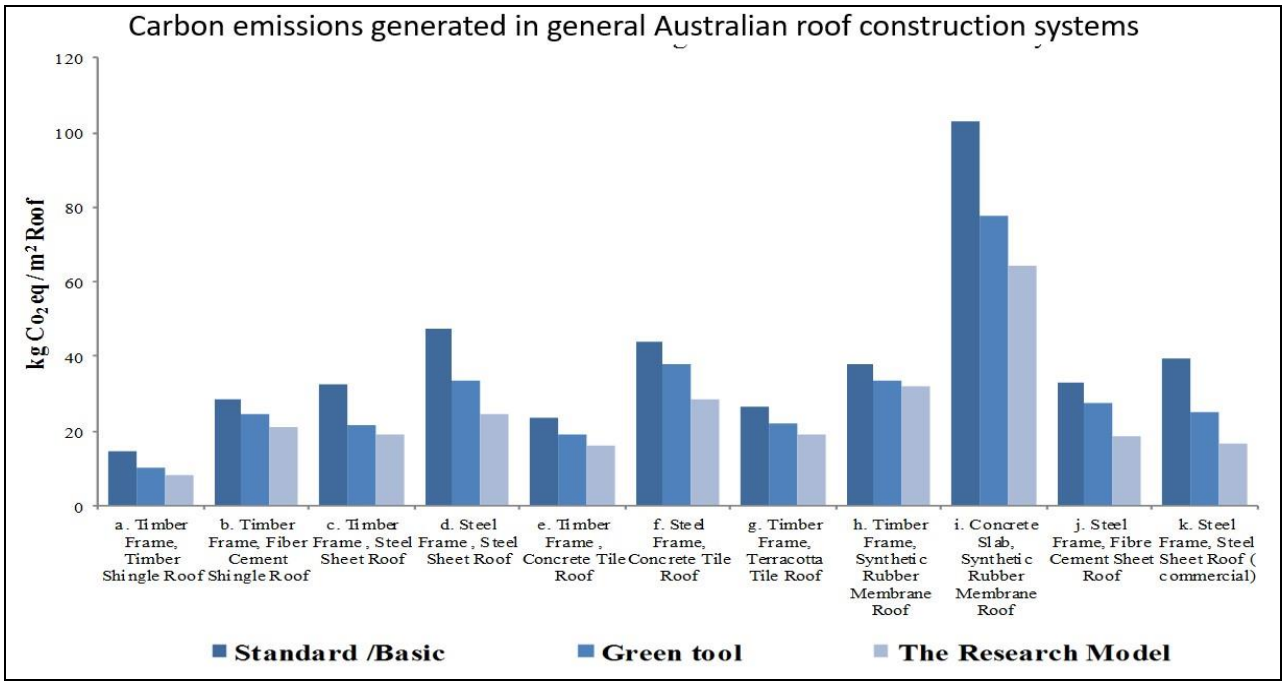

Figure 3: Bar graph of carbon emissions generated in general Australian **Roof** construction systems – comparing levels generated in standard/basic construction practice with those where the Green Star tool and the bioclimatic criteria of the Research Model have been applied.

Table 4: Potential carbon emission **reductions** in general Australian **Roof** construction systems

General Australian **Roof** construction systems	**Green tool** Carbon emissions	**Research model** Carbon emissions
	$KgCo_2/m^2$	$KgCo_2/m^2$
a. Timber Frame, Timber Shingle Roof	32.08 %	45.41 %
b. Timber Frame, Fiber Cement Shingle Roof	14.03 %	25.46 %
c. Timber Frame, Steel Sheet Roof	33.17 %	41.61 %
d. Steel Frame, Steel Sheet Roof	36.97 %	48.09 %
e. Timber Frame, Concrete Tile Roof	18.81 %	30.87 %
f. Steel Frame, Concrete Tile Roof	21.69 %	42.55 %
g. Timber Frame, Terracotta Tile Roof	16.66 %	29.00 %
h. Timber Frame, Synthetic Rubber Membrane Roof	11.69 %	15.69 %
i. Concrete Slab, Synthetic Rubber Membrane Roof	24.63 %	37.43 %
j. Steel Frame, Fibre Cement Sheet Roof	16.45 %	44.37 %
k. Steel Frame, Steel Sheet Roof (commercial)	36.32 %	57.40 %

Source: Derived from data set produced for doctoral research (Sattary 2017) (Supporting data and calculations available on request from author).

DISCUSSION

From the results described in the previous section, two trends are identified following application of the bioclimatic criteria of the research model to general Australian floor, wall and roof construction systems. First, application of the research model consistently produced (generated) the lowest carbon emissions as compared to standard building practice, or

following application of the Green Star environmental tool. Second, application of the research model consistently produced potentially higher percentage reductions in carbon emissions as compared to application of the Green Star tool.

These results suggest that consideration of bioclimatic design principles in the construction industry must be of high priority to reduce carbon emissions resulting from the building construction process. In fact, all the bioclimatic principles and techniques outlined in Table 1 are known and available, but are not being consistently and appropriately applied in existing Australian construction practice. If this were done, this would result in significant reduction in construction carbon emissions. Research thus needs to be conducted in Australia as to how these principles can best be implemented – as has been commenced in the United Kingdom (Allwood, 2012), (UK Indemand, 2014), (UK Indemand, 2015), (World Federation of Engineering Organization, 2011). Use of bioclimatic criteria could be encouraged by legislation granting green credits for recycling of materials such as are granted in environmental assessment tools (e.g. LEED, Leadership in Energy and Environmental Design; BREEAM, Building Research Establishment Environmental Assessment Method; and the Australian Green Star tool). This process could be further facilitated by creation and expansion of a 'warehouse of parts' and 'reuse markets' for supply of recycled building elements. There could also be expansion of deconstruction techniques, machinery and facilities (Bales, 2008), (SteelConstruction.info, 2014) (Bales 2008; Steel Construction Information 2014). The American Society for Testing and Materials (ASTM) also suggests that Portland cement should be replaced by geopolymer-based cements in construction processes (ASTM Inrenational, 2015).

The research model tool in this study proposes geopolymer cement as a replacement for Portland cement for structural and non-structural building purposes. Geopolymer cement was chosen rather than other green cements for two reasons. First, while there are other options available, geopolymer cement is currently by far the most common and widely used green cement in Australian construction, and its use is increasing. Second, geopolymer cement is the most appropriate green cement to consider from the viewpoint of reducing carbon emissions of construction. In respect to this, when used as a replacement for Portland cement, geopolymer cement produces a range of potentially high reductions in carbon emissions (75 to 90 percent). This variation is because GC can be fly-ash-based, slag-based or rock-based. Geopolymer cements made from fly ash or granulated blast furnace slag require less sodium silicate solution to be activated. They consequently have a lower environmental impact than GC made from metakaolin rock (i.e. rock-based geopolymer cement). However, the type of geopolymer cement that might be used to replace Portland cement in building construction ultimately depends on the type available in the area concerned (Habert , 2011). In turn, this will affect the outcomes where the research model is used, and this must be considered when the research model is applied.

This study considers only the first three stages of the building lifecycle, and only the main building elements of floors, walls and roofs. Future research using Building Information Modelling (BIM) and related software will extend this study to cover the entire building lifecycle and consideration of all building elements.

CONCLUSION

Our world is changing, and our construction industry needs to adapt to these changes. The Australian building sector has the largest potential for significant reduction of greenhouse gas emissions – which could be achieved by simple application of bioclimatic principles. The UK government has funded the UKIndemand plan to achieve 80 per cent reduction in construction carbon emissions by 2050 – which is considered an achievable target providing future design and construction of buildings take into account bioclimatic design principles (Allwood, 2012). Further action could involve creation of an 'Australian-Indemand' scheme by commissioning leading research groups to investigate the problem of reducing embodied energy and carbon emissions in the Australian building sector. This would enable the government to achieve significant reductions in greenhouse gas emissions toward the Paris agreement, and thus to reduce the carbon emissions of the building sector on the Australian environment.This research compared the potential reduction in construction carbon emissions achievable through standard building practice, use of the Green Star tool, and application of bioclimatic criteria within the research model. It was found that for floor, wall and roof materials of general Australian construction systems, the research model consistently produced the highest reductions in construction carbon emissions for all building elements considered – up to 57 percent reduction for some elements within floor and roof construction systems, and up to 93 percent for roof construction systems.

At the UN Climate Change Conference in Paris in 2015, the Federal Government agreed to reductions of 26 to 28 percent in Australian greenhouse gas emissions by 2030 (Hasham, 2015). Given that the Australian construction sector produces around 11 percent of the country's greenhouse gas emissions (Australia Climate Works, 2010), consideration of bioclimatic design principles in building design and construction processes should be an important part of this process to reduce Australia's carbon emissions.

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ESTIMATING EMBODIED CARBON EMISSIONS OF BUILDINGS IN DEVELOPING COUNTRIES: A CASE STUDY FROM SRI LANKA

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Keywords: Cradle to Gate, Embodied Carbon Estimation, Sri Lanka, Structural Elements.

Abstract

Even with the increasing attention on reduction of Embodied Carbon (EC) emissions in the global built environment sector, yet most of the developing countries focus only on reduction of Operational Carbon (OC) through improved operational energy performance. The significance of EC estimation and reduction in buildings in these countries are yet to be fully realised. Therefore, this paper provides a case study of an office building located in Western province in Sri Lanka, which is used as a drive to identify the potential for estimating EC emissions of buildings in developing countries. Accordingly, the estimation was carried out confining to the cradle to gate system boundary and structural elements of a building. The estimation process revealed that the EC estimation is a challenging process for a developing country like Sri Lanka as it encountered many challenges such as lack of accurate and up to date EC co-efficient for building materials, time consuming and work intensive nature of estimation, difficulty in choosing a system boundary and unavailability of an appropriate estimation tool. The case study findings revealed that the total structural elemental EC emission per gross floor area is 191.11 kgCO2/m2. Similar to many previous studies, it was identified that the top most EC intensive element of this building is also substructure. However, this study was carried out as a pilot study of a further research and can be extended to incorporate all the elements of the building to provide an accurate value for the overall and elemental EC emissions.

INTRODUCTION

The building sector is known to be one of the largest contributors to global carbon emissions. It is responsible for more than one third of total global energy use and carbon emissions (Peng, 2015). In the light of that fact, the building sector has been targeted as a major sector in achieving the global carbon emission reduction targets introduced in Kyoto protocol and then Paris agreement by UNFCC, 1998, 2012 and 2016 (IPCC, 2014). Accordingly, low carbon/green building transition plans have been put forth around the world as one of the main building carbon reduction strategies. Though it has allowed most of the developed and developing countries to reduce the share of OC through increasing operational energy efficiency, it has caused the proportion of EC in the total carbon emission of buildings to increase (RICS, 2012). With the recognition of that, reducing EC emissions of buildings has presently received much attention of environmentally advanced developed countries (RICS, 2012). However, the existing literature indicates that the impact of EC emissions has not yet been fully recognised in developing countries and as a result, EC estimation and reduction have been overlooked.

Being identified that EC estimation is the drive towards EC reduction, this paper attempts to identify the potential for estimating EC emissions of buildings in developing countries. For that purpose, the paper explores a case study of office building located in Western Province in Sri Lanka.

Sri Lanka is a developing country which has recently taken number of initiatives in promoting sustainable/green buildings in the country (Green Building Council, 2015). That can be considered as a prudent step in achieving the carbon reduction target (20% from energy sector and 10% from other sectors by 2030) which has been set in compliance with Paris Agreement in 2016 (Climate Change Secretariat, SL, 2017). As a main initiative, Green Building Council of Sri Lanka, the leading authorised body in promoting green buildings has introduced Green SL rating system for built environments in 2015. Though, there are many provisions for OC emission reduction, there are no direct provisions to account EC emissions. Therefore, it was considered Sri Lanka as an appropriate developing country to conduct this study.

The paper is organised into six main sections. The first section briefly introduces the aim of the study. Then, it discusses the literature findings in two sections as significance of EC in buildings and EC estimation. The methodology adopted to conduct the research is presented under the research method section. The subsequent section presents the research findings and analysis and final section draws the conclusions.

SIGNIFICANCE OF EMBODIED CARBON IN BUILDINGS

A building, within its whole life cycle emits two types of carbon namely; operational and embodied carbon (RICS, 2012). Operational Carbon (OC) is the emission occurs during the operational phase of a building and is typically generated from operational energy use for heating, cooling, ventilation, lighting, ICT equipment, cooking and refrigeration appliances etc. (RICS, 2014). Due to various measures that have been taken to regulate operational carbon of buildings during last few decades, building owners have been able to increase the efficiency of operational energy and carbon, creating the EC share of whole life cycle carbon of buildings to increase largely (RICS, 2014).

EC is the emission released during the production of a building material, component, or the entire building. It encompasses carbon emitted during material extraction, transportation, manufacturing, distribution, construction/assembly, building maintenance, construction demolition and disposal (RICS, 2012). Unlike OC which has the opportunity to improve at any point in the lifetime of a building by implementing a range of energy efficiency measures, embodied carbon cannot be reversed. Once they have been released the opportunity for improvement has passed (Jones, 2016).

Figure 1 indicates the proportion of OC and EC to the whole life cycle carbon of three types of buildings. According to that, typical buildings (Office, supermarkets and semi-detached houses) account for 80% of OC and only 20% of EC. However, when the buildings transform from typical buildings to either low carbon or zero carbon buildings, it indicates that the EC proportion has increased, making it as the main type of carbon to be managed.

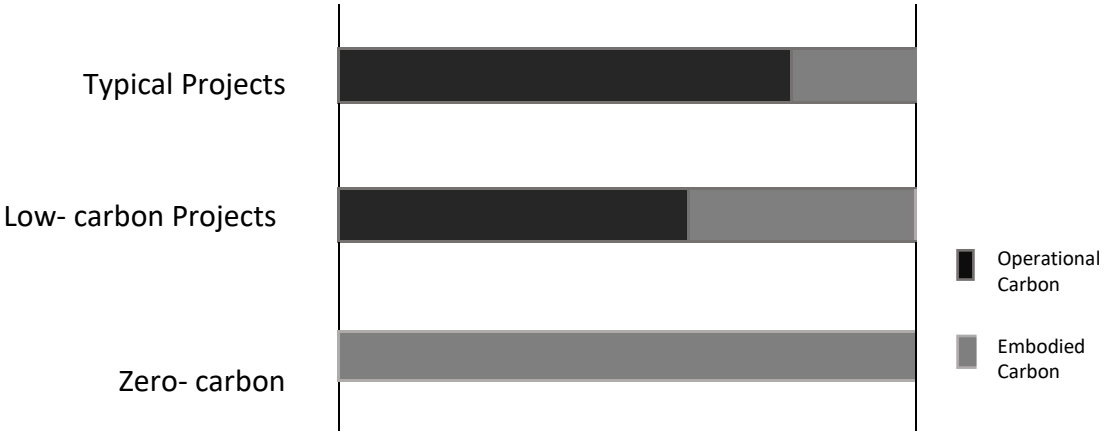

Figure 1: Proportion of OC to EC
(Adapted from: RICS, 2012)

Another factor that makes the EC important is the target set by Paris Agreement (UNFCC, 2016) to ensure that every single building produces zero carbon emissions by 2050. It has been able to gain the attention of both the construction sector and the governments of environmentally advanced countries such as the Western Europe, Australia, New Zealand, Canada, and the USA towards EC reduction (WGBC, 2017).

Embodied Carbon Estimation

The main drive towards EC reduction is carbon estimation (Nawarathna et al., 2018). Unlike OC estimation practices, EC estimating is not yet a developed process (Victoria and Perera, 2018). Despite a growing set of guidance that have been introduced by European standards, national organisations and professional bodies (Giesekam and Pomponi,2017), the existing literature presents many challenges in estimating EC such as unavailability of a standardised methodology, difficulty in choosing an estimation boundary, lack of national databases for carbon emission factors, out of date assessment tools, lack of open source assessment tools, benchmarks and EC data (Nawarathna et al., 2018).

EC emission is associated with all the phases of a building life cycle. Although it is important to account all lifecycle stages in the assessment to get an accurate total EC emission for a building, limited data availability (mainly the EC co-efficient values of building materials and activities) has made to define a measurement boundary prior the estimation. As it is illustrated in Figure 2, there are five system boundaries in EC estimation namely; cradle (earth) to gate (manufacturing factory gate), cradle to site (construction site), cradle to end of construction, cradle to grave (demolition), or even cradle (earth) to cradle (reuse, recycle and recovery) (RICS,2012).

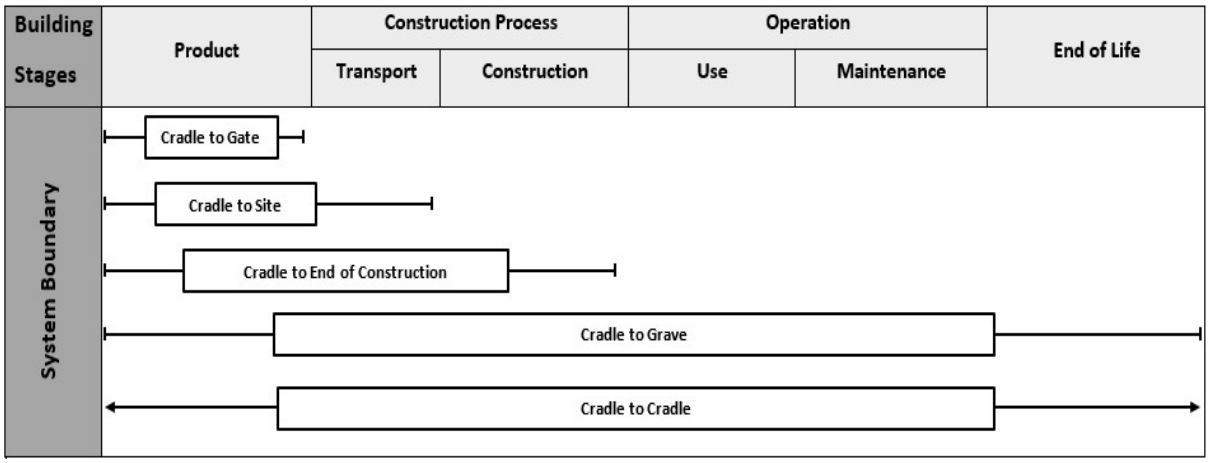

Figure 2: System Boundaries of EC Estimation
Adapted from: RICS (2012)

In association with EC estimation, few EC coefficient databases have been developed. However, almost all of them cover only the cradle to gate system boundary and they have failed to include emissions from latter stages of life cycle (such as construction, operation & maintenance and demolition & disposal) as they are project specific emissions (Hammond and Jones, 2011). Few examples of EC inventories are shown in Table 1.

Table 1: EC Inventories
Adapted from: Nawarathna et al., (2018)

Inventory/Database	Access	System Boundary	Country
Bath Inventory of Carbon and Energy	Open	Cradle to Gate	UK
Athena Life Cycle Inventory Product Databases	Licensed	Cradle to Gate	USA, Canada
New Zealand Building Materials Embodied Energy Database	Open	Cradle to Gate	New Zealand
Hutchins UK Building Black book	Licensed	Cradle to Gate	UK
European Life Cycle Database (ELCD)	Open	Cradle to Gate	Europe
EcoInvent 3.3	Licensed	Cradle to Gate	Switzerland
ÖKOBAUDAT (German National Database)	Open	Cradle to Gate	Germany
AusLCI	Open	Cradle to Gate	Australia

Even with many challenges and limitations as mentioned above, studies are being conducted to estimate the EC in various buildings under different system boundaries. Table 2 summarises some of those prior studies that have been conducted to the UK context.

The scope of all these studies have mainly limited to the carbon hotspots which have been mentioned by the RICS (2014). RICS (2014) recommends that substructure (foundations, basement retaining walls and ground floor construction), superstructure (frame, upper floors, roof, stairs and ramps, external walls, windows and external doors, internal walls and partitions), internal finishes (wall finishes, floor finishes, ceiling finishes) and external works as carbon hotspots that fundamentally need to be included in EC calculations.

It is to be further noted that all these assessments have been conducted during the use stage of buildings due to the data availability. Though it is easy to estimate the EC at this stage as most of the required data are available, it limits the opportunity to implement EC reduction strategies. Therefore, RICS (2012) recommends to exercise EC estimation during early stage of design in order to achieve high EC emission reduction.

Table 2: Previous EC Studies

Study	System Boundary	Type of Buildings
Pomponi, Moncaster and Wolf (2018)	Cradle to Gate	An Office building Refurbished residential Transport Infrastructure, Residential and a Retail
Hakkinen et al. (2015)	Cradle to Gate	A Residential building
Victoria et al. (2015)	Cradle to Gate	An Office building
Sansome and Pope (2012)	Cradle to Grave (excl. maintenance and deconstruction)	Five types of commercial buildings (Distribution Warehouse, Supermarket, Secondary School, Office, Mix Development)
Target Zero (2012)	Cradle to Grave	An Office building
Bennett (2010)	Cradle to Site	Two typical office buildings
Sturgis and Roberts (2010)	Cradle to Grave	An Office building

RESEARCH METHOD

This study analysed the EC of an office building located in the Western province in Sri Lanka. Since most of the prevailing EC studies have been conducted to carbon intensive building elements, this study was also focused on carbon hotspots, but limited to main structural elements that make the skeleton of a building. Accordingly, it was selected the substructure, frame, upper floors, external walls and roof in compliance with BCIS element classification.

This study was limited to the cradle to gate system boundary. The Bills of Quantities (BOQs) and architectural drawings of the building were refereed to obtain the building specific data such as used building materials with their quantities and building morphology parameters.

Due to the unavailability of an up-to-date country specific EC- coefficient database, two databases were adapted; an international level one (the Inventory of Carbon and Energy (ICE) version 2.0, 2011) and a national level one which has been developed by Poliyadda (2000). Although the latter is a national level database, it is relatively an older database which has not been recently updated and does not provide EC co-efficient for all materials. Therefore, only the data of country specific production materials such as sand, random rubble, bricks and timber were taken from that and the rest were extracted from ICE (2011). The materials and their quantities which were provided in various units (m^3, m^2, tonnes, and m) were converted in to mass in kilogram to comply with adapted EC databases and to maintain the consistency of the estimation. The conversion was based on the BS 648:1964: Schedule of weights of building materials. Eventually, the estimation was conducted using Equation *(1)* and MS- Excel software.

$$TEC_{SE} = EC_{sub} + EC_{fr} + EC_{uf} + EC_{Ew} + EC_{rf} \quad (1)$$

Where, TEC_{SE} is Total Embodied Carbon of structural elements; EC_{sub} is Embodied Carbon of substructure; EC_{uf} is Embodied Carbon of upper floors; EC_{fr} is Embodied Carbon of frame; EC_{ew} is Embodied Carbon of external walls and EC_{rf} is Embodied Carbon of roof

RESEARCH FINDINGS AND ANALYSIS

Case Description

The selected building was an office building located in the Colombo suburbs, Western province in Sri Lanka. It is a building in which the building foot print covers 866.29 m^2 and extended vertically over 19.017 m. It accommodates 4 stories including the ground floor while providing internal total gross floor area of 2629.26 m^2. The vertical and horizontal structural beams and columns have been strengthened using reinforced concrete in which a raft foundation width stand the structural load of the building and its other associate forces. Calicut tiles have been used to cover the roof area of 615.29 m^2 of the building while brick work being used to cover the building face area of 607.13 m^2. The main building materials that have been used for the selected structural elements are listed in Table 3.

Table 3: Building Materials used for Structural Elements

Building Element	Main Building Materials
Substructure	Concrete (G 15), Reinforced Concrete (G 25) Mortar, Rubble, Sand, DPC
Frame	Reinforced Concrete (G 25)
Upper floors	Reinforced Concrete (G 25), DPM
External Walls	Bricks, Mortar
Roof	Reinforced Concrete (G 25), Steel, Timber, Calicut Clay Tiles, PVC (110mm)

Elemental EC Emissions

Table 4 and Figure 3 present the total elemental EC and EC per Gross Internal Floor Area (GIFA) of the building. As per RICS (2012), GIFA is used as a standard metric for benchmarking, estimating and cost planning purposes in the construction sector. Further, they mention that it is a clear measure for comparison across all buildings all buildings regardless of their function, design or specification. Therefore, EC per GIFA of the elements of this building was also calculated for the purpose of comparison with other studies.

Table 4: Elemental EC emissions

Elements	Elemental EC ($kgCO_2$)	EC per GIFA ($kgCO_2$/m2)
Substructure	**217,407**	**82.68**
Frame	**95,977**	**36.50**
Upper floors	**150,760**	**57.33**
Roof	**29,111**	**11.072**
External Walls	**9,268**	**3.525**
Total	**502,523**	**191.11**

The fingdings revealed that substructure emits 82.68 of EC $kgCO_2/m^2$, placing it on the top of the elemental embodied carbon emission hierarchy of this case study. This is mainly due to the heavy use of steel and concrete (two types of high carbon intensive materials) in the substructure compared to other elements. The rest of the structural elements; upper floors, frame, roof and external walls placed respectively in the hierarchical order. Accordingly, it was identified that the highest carbon intensive element of this building is the substructure.

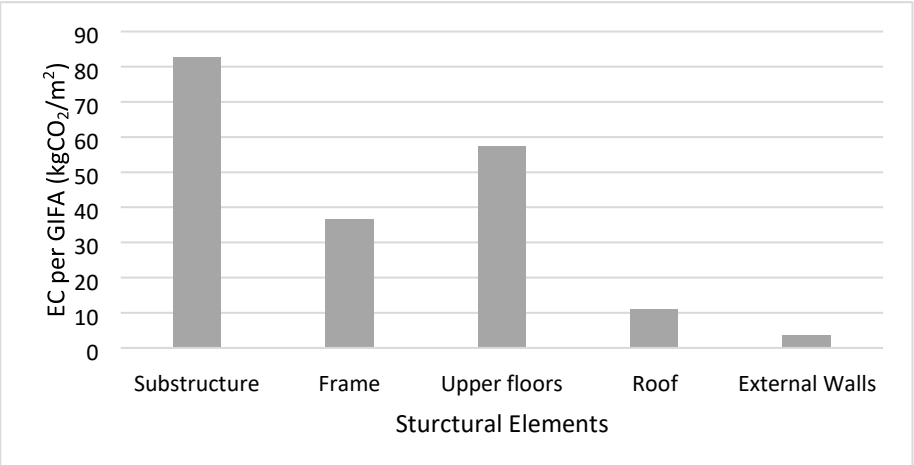

Figure 3: Elemental EC Emissions

Even when analysing the studies that have been mentioned in the Table 2, it was noted that substructure is the highest carbon intensive element among these five main structural elements, regardless of the type, location of the building and the system boundary of the

estimation. However, it was difficult to understand the elemental hierarchy of these studies, as most of them have considered upper floors, external walls, frame and roof under the category of superstructure.

For the purpose of comparison, author was able to find out a similar type of case study which has been carried out for an office building located in the UK by Victoria et al., (2015) under the same system boundary of cradle to gate. Compared values are presented in Table 5. It indicates that the hierarchy of the carbon hotspots is different, though the both studies have been carried out to the same type of building within the same system boundary. RICS (2014) mentions that carbon hotspots and the hierarchy may vary from one project to the other and from one building to the other due to heterogeneity of projects.

Table 5: Hierarchy of Elements

Base Case Study (SL)		Victoria (2015) UK	
Substructure	43%	Substructure	47%
Upper Floors	30%	Upper Floors	22%
Frame	19%	Frame	21%
Roof	6%	External Walls	9%
External Walls	2%	Roof	1%

Challenges Encountered

The main purpose of this study was to understand the potential for estimating the EC of buildings in developing countries. Such estimation was not straightforward, and several challenges were encountered.

First, the major challenge was the unavailability of an up- to- date EC co- efficient database with all building materials for Sri Lankan context. Therefore, the study adopted two databases as necessary. This emphasised the necessity of a new national level database to estimate the EC accurately.

Another challenge confronted was the need to identify building materials and separate them into structural elements and then convert the various material unit quantities in to mass (kg) to comply with EC databases. This was time consuming and work intensive activity. As the BOQs of the selected case study was in compliance with NRM and the EC values in the inventories were for building materials, there might be missed materials in the estimation.
However, care was given not to exclude any significant item or material from the estimation.

CONCLUSIONS

The significance of EC estimation and reduction of buildings in the developing countries are yet to be fully realised. Therefore, this study was conducted to understand the possibility of conducting EC estimation to developing countries.

The EC estimation process revealed that estimation is yet a challenging process to a developing country like Sri Lanka. It pointed out the necessity of a country specific, up to date database for material EC co-efficient in order to achieve realistic EC estimation. Therefore, further researches are required to explore and develop the existing country specific database. Further, it emphasised the necessity of a straightforward estimation method as the method used in this study was complex and time consuming.

Similar to previous studies, the findings of this study also revealed that the highest embodied carbon intensive structural element is substructure. That may be mainly due to use of extensive amount of concrete and steel in which the carbon contents are very high. Therefore, it is recommended to design the buildings with less quantities of materials and use alternative low carbon materials to save EC emissions in substructure. Few studies have been conducted in Sri Lanka to identify alternative materials with lower embodied carbon emissions yet, further researches are required to explore more design and material alternatives.

This study was conducted as a pilot study of an ongoing research. It limited to cradle to gate system boundary and structural elements of the selected building. Stairs and ramps, doors and windows, internal walls and partitions, internal finishes, fittings, furnishings and equipment, services and external works were excluded. Therefore, future work can be extended to incorporate these areas as well to provide more representative value for the overall and elemental EC emissions of the building.

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THE METABOLISM OF BUILT ENVIRONMENT: ENERGY FLOW AND GREENHOUSE GAS EMISSIONS IN NIGERIA

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Keywords: Energy flow, Environmental impact, Greenhouse gas emissions and Sustainability.

Abstract

It is becoming increasingly clear that the consumption of resources now enjoyed in developed nations will be impossible to be sustained worldwide. While developing countries still have the advantage of low consumption and a smaller ecological footprint per person, they cannot simply develop in the same way as other western cities have developed in the past. The severe reality of population and consumption inequalities makes it contentious whether studies done in developed countries can be translated and applied to developing countries. This research set itself apart by examining the flow of energy in Nigeria and the impact that the flow will have on the environment. A simplified version of an intergovernmental panel on climate change (IPCC) method for inventorying GHG emissions is adopted for this research. Nigeria being a developing country with no country specific, technology specific and facility specific emission factor, thus Tier 1 method seems more appropriate for this research. Additionally, the use of national fuel delivery statistics becomes more practicable in a developing country like Nigeria. Thus activity data used in this paper are derived from energy statistics, compiled by the national statistical agencies such as National Bureau of statistics (NBS), National Population Commission (NPC), other data sources include from Department of petroleum Resources (DPR), the Petroleum Products Pricing Regulatory Agency in Nigeria (PPPRA), Nigerian Electricity Regulatory Commission (NERC) and Nigerian National Petroleum Corporation (NNPC). The results reveal low primary energy consumption in Nigeria as compared to its population with consumption standing at 2,462,794TJ. While the corresponding GHG emissions as compared to the consumption of primary energy is high, it currently stand at 289, 154 (Gg CO2), 44 (Gg CH4) and 4 (Gg N2O). The three largest energy sources in Nigeria are biomass, liquid fuels and natural gas contributing about 36%, 31% and 30% share of energy respectively. Moreover, the findings reveal that the single largest contributor of greenhouse gas emissions in Nigeria is the biomass. It contributes about 36% of the carbon emissions, 65% of the methane emissions and 88% of all nitrogen oxide emissions in Nigeria. Followed by the exploration and flaring of natural gas. Thus the combined emissions from biomass and production of crude oil/natural gas are responsible for two-third of the carbon emissions, nine-tenth of the methane emissions and about nine-tenth of Nitrogen oxide emissions. Furthermore, by substituting biomass fuel with a carbon lean fuel such as natural gas, would lead to overall reduction of carbon emissions by 18%, methane emissions by 63% and Nitrogen oxide by 85%. Since, the combustion of biomass and inefficient exploration of oil/gas appears to be the greatest contributor of GHG emissions in Nigeria, the paper suggest some sustainable options that would lead to the reduction of GHG emissions. These options include the use of more efficient technology in the exploration of oil/gas and the transitioning from biomass fuel to more environmentally friendly fuel such as natural gas.

INTRODUCTION

An increasing number of emerging studies are indicating that the depletion of exhaustible resources are now occurring at a rates dangerously high and there is lack of clear signal to identify the level of exhaustion of nonrenewable or slowly regenerating resource. Globally, 500 exajoules of primary energy and 60 billion tonnes of raw materials were used annually, with material extraction having doubled since 1995 (Krausmann et al., 2009). Furthermore, the primary energy consumption of USA in 1995 is more than one quarter of the global supply, China's consumption had tripled from 857 million tonnes oil equivalent (MTOE) to 3014 MTOE over the last two decades (BP, 2002 and BP, 2016). While Africa with 1.2billion population consumed 435MTOE which is 5 times less than the consumption of the USA (BP, 2002; BP, 2016 and UN DESA, 2015). This pattern of excessive consumption by developed/fast developing countries as compared to developing countries has driven large-scale deforestation, a reduction of wilderness areas and biodiversity loss and an increase in soil degradation, groundwater contamination, groundwater depletion and production of large amounts of often hazardous wastes (Krausmann et al., 2009).

Although humans have altered their physical environment throughout their history, there has never been anything like the 20th century (McNeill, 2000). For instance, during the last century humans have increased their materials use 8-fold and energy use 16-fold, generating the release of some 160 million tons of sulphur dioxide emissions per year, more than twice the sum of natural emissions (Krausmann et al., 2009 and Crutzen, 2002). This development paradigm is absolutely unsustainable and requires urgent rethinking. While developing countries still have the advantage of low consumption and a smaller ecological footprint per person, they cannot simply develop in the same way as other western cities have developed in the past. Wackernagel and Rees (1996) asserts that there is considerable resource consumption variability between developed and developing countries. Krausmann et al., (2009) further developed the distinction in consumption practices by reporting that while the population grew by a factor of two faster in the so called "developing world" than in the industrialized countries. In contrast, the metabolic rate increased much faster in the industrialized countries than in developing world. Crutzen (2002) assert that the impact on the planet's ecological systems of the 25% of the world population are almost exclusively responsible for all ecosystem degradation.

In comparison between the world eight G8 countries plus China with the remaining countries of the world in Greenhouse Gas (GHG) emissions CAIT Climate Data Explorer (2017) result shows that the the GHG emissions from the world eight G8 countries plus China is more than the total emissions from the remaining countries of the world. Additionally, while all the wealthiest G8 countries have succeeded in reducing their GHG emissions below the 1990 level, the top 5 emerging economies (China, Brazil, Mexico, South Africa and India) have not shown to abide by such commitment. To the contrary, they almost doubled their GHG emissions above the 1990 level. For instance, China tripled their emission level from 3153(MMTCO2e) to 11,735MMTCO2e, India doubled their emission level from 1189 to 2909MMTCO2e. Same goes for Brazil, South Africa and Mexico (CAIT Climate Data Explorer, 2017). The consequences of this, among others are, acid precipitation, photochemical 'smog' and climate warming Crutzen (2002) other consequences include erosion, global warming, climate variability, climate

change, desertification and flooding (Audu, 2013). Despite wide recognition of this urgent environmental issue, there are few or no studies of Energy metabolism in Nigeria. The few researches that are available in Nigeria are mostly fuel or sector specifics such as trends in biomass consumption, fuel wood consumption, potential of renewable energy resources, determinant of GHG emissions, energy consumption and economic performance in Nigeria e.t.c., which will not accurately capture the environmental impact of energy flow and GHG emissions in Nigeria. For instance, Gujba et al., (2015) assessed the environmental and economic sustainability of the household cooking Sector in Nigeria. Achike et al., (2014) study the determinants of Greenhouse Gas emissions in Nigeria and its implication for trade and climate change, Mohammed et al., (2013) reviewed the potential for renewable energy resources in Nigeria; Zaku et al., (2013) appraised the energy ladder and wood fuel consumption in Nigeria, similar researches were conducted by Audu (2013), Itanyi and Ugwuanyi (2014). Sa'ad and Bugaje (2016) investigates the trends of biomass consumption in Nigeria, Kuponisi (2004) work on the status of renewable energy in Nigeria, Oladeji (2014) conduct an overview on renewable energy as a solution to Nigeria's perennial energy problems. Sambo
(2005) study the perspective of Nigerians on renewable energy for rural development. Odularu and Okonkwo (2009) assessed the contribution of energy consumption on economic performance in Nigeria. Olise and NriaDappa (2009) study energy crises and utilisation of associated gas and renewable energy resources in the Nigeria.

Additional to this lack of holistic research on energy, the consumption pattern of energy in Nigeria have not shown to go in line with the principles of sustainability. Being the largest oil producer in Africa and the world's fourth-largest exporter of liquefied natural gas (LNG) in 2015 (Organization of the Petroleum Exporting Countries (OPEC), 2017; Central Intelligence Agency (CIA), 2017; BP, 2016) yet, 55% of the population has no access to electricity (IEA, 2014; Ishola et al., 2013) and 87-95% depend on biomass for fuel wood (Sa'ad and Bugaje, 2016). More worrisome is the increasing number of emerging reports that are indicating rapid rise in biomass consumption in Nigeria. IEA (1990; 2014) have reported significant rise in fuel wood consumption from 51,527ktoe in 1990 to 100,124ktoe in 2014. At this rate of consumption and with the country projected to be the world's third most populous country by the year 2050, Nigeria cannot afford to develop at this current rate of environmental degradation. This is more true as Nigeria seeks to become one of the 20 largest economies in the world, raise living standards and expand access to electricity to 75 per cent of the population in its growth and development agenda agenda (Ministry of Budget and National Planning, 2008). While achieving this developmental goal is paramount, a good understanding of the trade-offs between economic growth and development aspiration on the one hand, and climate change issues on the other is needed. This research set itself apart by examining the flow of energy in Nigeria and the impact that the flow will have on the environment. In line with this, the study quantify the level and pattern of energy consumption and GHG emissions in Nigeria. The outcome of the study will help policy-makers to target cleaner energy generation that would reduce GHG emissions and its corresponding environmental impact.

METHODOLOGY

This paper investigates the metabolism of energy in Nigeria through a three-part methodology. The first step involved selecting and defining the study area. The second step involved deciding on the method to adopt in calculating energy and GHG emissions in Nigeria. The third step involved deciding on the data and of source of data to consider.

First, we began by defining the study area, Nigeria is Africa's most populous country, with currently more cities with over a million people than in any other nation on the continent (Maconachie, and Binns, 2006). It is the continent's most prolific oil-producing country, which, in its mix of conventional energy reserves, is simply unmatched by any other country on the African continent (NBS, 2016). Nigeria's proven crude oil reserves are estimated at about 37.45 billion barrels, with proven natural gas reserves of 5,475.2 billion cubic metres, while coal and lignite reserves at about 2.734 billion tonnes (Organization of the Petroleum Exporting Countries (OPEC) 2017; CIA, 2017). With this considerable reserves of energy resources and with it being the most populous African country with economy that is the second biggest, Nigeria is the ideal place for this research. This is due to the understanding that countries with large economy and dense populations, are ideal places to examine sustainability strategies. Hence the choice of Nigeria for the study.

Second, the three commonest methodologies for inventorying GHGs are International Council for Local
Environmental Initiatives (ICLEI), the Greenhouse Gas Regional Inventory Process (GRIP) and the Intergovernmental Panel on Climate Change (IPCC) (Sówka and Bezyk, 2017). The first two are more suitable for inventorying GHG emissions in local governments/regions of different countries, the latter is internationally-accepted methods used to calculate GHG emissions and sinks for different countries of the world. This is because it provides a standard that aids in uniformity and consistency in greenhouse gas studies, it also ease in comparison of GHG emissions with cities and nations across the globe. For this study a simplified version of an intergovernmental panel on climate change (IPCC) method for estimating the GHG emissions is adopted. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines) provide methodologies for estimating national inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases. It provides three methods of calculating GHG emissions depending on the national circumstances and data availability. The three methods outlined by IPCC are:

1) Tier 1; 2) Tier 2 and 3) Tier 3.

Nigeria being a developing country with no country specific, technology specific and facility specific emission factor, thus Tier 1 is adopted for this research.

Additionally, the IPCC, 2006 guidelines outline the energy sector mainly to comprise of exploration and exploitation of primary energy sources, conversion of primary energy sources into more useable energy forms in refineries and power plants, transmission and distribution of fuels, use of fuels in stationary and mobile applications. Hence this research is restricted to the energy sector, this is due to the understanding that about 75% of all GHG gas emission are being attributed to the energy sector. The sector is also reported to contribute over 90 percent of the CO2 emissions and 75 percent of the total greenhouse gas emissions in developed countries (IPCC, 2006).

While the IPCC guidelines uses standardized field data which requires a great deals of details but developing countries such as Nigeria cannot keep up to such details due to data scarcity. The paper strictly go by the guidelines wherever possible, however, where lack of data would not allow for the guidelines to be followed a simplified version of the guidelines is adopted. Furthermore, based on the Kyoto Protocol classification system, the most important direct greenhouse gases emitted by humans include carbon dioxide (CO2), methane (CH4), nitrogen oxide (N2O), and several fluorine-containing halogenated substances (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (Depledge, 2000). But for this research only carbon dioxide (CO2), methane (CH4) and nitrogen oxide (N2O) are considered. GHG emissions from all components of the economy are determined by fuel types: liquid fuels, solid fuels, natural gas (dry) and biomass rather than by sectors for reason indicated above. Furthermore due to data scarcity only emissions from gas flaring and reinjection in the production/extraction of the primary fuels are considered for this work. Also, the reporting tables of the IPCC guidelines are adopted in this work wherever possible, this is to ensure that inventories are reported in a standard format and to facilitate consistency between countries, categories and to enable ease of comparison with other countries.

Third step, while going house by house, industry by industry, vehicle by vehicle to collect actual fuel combusted will produce more accurate result and even avoid double counting in emission estimates, it is laborious and even impractical to collect data like this in a country like Nigeria with a population of over 181million and total land area of around 970million square kilometres National Bureau of Statistics (NBS). (2016). Thus the use of national fuel delivery statistics become more practicable in a developing country like Nigeria. Additionally, the quantities of fuel used in the calculations where based on the quantities delivered for consumption not the actual consumption, while It is good practice to use, where possible, the quantities of fuel combusted rather than the quantities of fuel delivered but lack of data in Nigeria will not allow that. Furthermore, the activity data used in this paper are derived from energy statistics, compiled by the national statistical agencies such as National Bureau of statistics (NBS), National Population Commission (NPC), other data sources include from Department of petroleum Resources (DPR), the Petroleum Products Pricing Regulatory Agency in Nigeria (PPPRA), Nigerian Electricity Regulatory Commission (NERC), Nigerian National Petroleum Corporation (NNPC) and from literature review such as works by Kuponisi, 2004; Sambo, (2005); Zaku, et al. (2013) and Oladeji, (2014) e.t.c. Unless where the required data cannot be found, then data from international publications, such as from International Energy Agency (IEA), the United States Energy Information Administration are used.

RESULTS AND DISCUSSIONS

Upon establishment of the energy consumption, they were studied to bring out likely patterns of the consumption. The results arrived for each fuel combusted is then converted into tera joules before multiplying by the corresponding emission factor to get the resulting emission from each greenhouse gas, this is further illustrated in equation 1 below as obtained from (IPCC, 2006) as follows:

Greenhouse Gas Emissions From Fuel Combustion

Equation 1:

$$Emissions_{GHG,\,fuel} = Fuel\ Consumption_{fuel} * Emission\ Factor_{GHG,\,fuel} \quad (1)$$

Where:
$Emissions_{GHG,\,fuel}$ = emissions of a given GHG by type of fuel (kg GHG)
$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emission\ Factor_{GHG,\,fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ).
Emission factors come from the default values provided together with associated uncertainty range in IPCC guidelines
To calculate the total emissions by fuel source, the individual emissions from each fuel in equation 1 is summed as shown in equation 2 to give the total emissions from the energy sector.

$$\boldsymbol{Emissions_{GHG} = \sum_{fuels} (Emissions_{GHG,uel})} \quad \textbf{(2)}$$

Table 1: Liquid Fuels Flow and Greenhouse Gas Emissions in Nigeria

Sector	Energy								
Category	Fuel combustion activities								
Sheet	(CO2, CH4 and N2O from fuel combustion by source categories – Tier 1)								
	Energy consumption			CO2		CH4		N2O	
	A	B	C	D	E	F	G	H	I
	Consumption	Conversion Factor(b)	Consumption	CO2 Emission Factor	CO2 Emissions	CH4 Emission Factor	CH4 Emissions	N2O Emission Factor	N2OEmissions
	(MT)	(TJ/Mt)	(TJ)	(kg CO2/TJ)	(Gg CO2)	(kg CH4/TJ)	(Gg CH4)	(kg N2O /TJ)	(Gg N2O)
			C=A*B		E=C*D/106		G=C*F/106		I=C*H/106
Liquid fuels									
Crude Oil									
[1]Motor Gasoline	13,406,409.57	0.035	469224.335	69300	32517.24641	3	1.407673005	0.6	0.281534601
Aviation Gasoline					0		0		0
[1]Jet Kerosene	440,689.20	0.034	14983.4328	71500	1071.315445	3	0.044950298	0.6	0.00899006
[1]Other Kerosene	1,693,774.06	0.038	64363.41428	71900	4627.729487	3	0.193090243	0.6	0.038618049
[1]Gas / Diesel Oil	4,037,536.16	0.038	153426.3741	74100	11368.89432	3	0.460279122	0.6	0.092055824
[1]Residual Fuel Oil	63,540.19	0.04	2541.6076	77400	196.7204282	3	0.007624823	0.6	0.001524965
Total					49781.90609		2.113617491		0.422723498
	A	B	C	D	E	F	G	H	I
	Consumption	Conversion Factor(b)	Consumption	CO2 Emission Factor	CO2 Emissions	CH4 Emission Factor	CH4 Emissions	N2O Emission Factor	N2OEmissions
	(103 m3)	(TJ/103 m3)	(TJ)	(kg CO2/TJ)	(Gg CO2)	(kg CH4/TJ)	(Gg CH4)	(kg N2O /TJ)	(Gg N2O)
[1]Natural Gas Liquids	2,389	28.44	67949.20976	64200	4362.339266	3	0.203847629	0.6	0.040769526
					0		0		0
Total for Liquid fuels					54144.24536		2.31746512		0.463493024

Source:(1)Department of Petroleum Resources Annual Oil and Gas Report, 2015; IPCC Guidelines for National Greenhouse Gas Inventories, 2006

The dominants liquid fuels used in Nigeria in the year 2015 are indicated in table 1 above, motor gasoline top the chart of consumed fuel with energy production of 469,224TJ and a corresponding CO2 emissions of 32,517 (Gg CO2) accounting for two third of all emissions in liquid fuels. This is more so with methane and nitrogen oxide with emissions from this gases accounting for 67% each of all emissions in liquid fuels. Gas/Diesel is the second most consumed fuel on the list with 153,426TJ of energy arising from the use of this fuel. The fuel generates carbon emissions of 11,368 (Gg CO2) which is one fifth of all carbon emissions in liquid fuel. NGL is third most consumed fuel, while household kerosene comes forth in terms of consumption and energy generating ability, but surprisingly household kerosene has more

carbon emissions than the NGL by more than 265 (Gg CO2) which is more than the national emissions generated from the consumption of residual fuel oil in Nigeria. The total emissions arising from Liquid fuels for the three most important greenhouse gases emitted by humans are 54,144 (Gg CO2), 2.32 (Gg CH4) and 0.46 (Gg N2O).

Table 2 shows the GHG emissions attributable to coal consumption in Nigeria. Despite the higher carbon fraction of coal as compared to other fossil fuels, as reported by (Spliethoff, 2010) it however contribute the least GHG emissions in Nigeria with carbon print of 129 (Gg CO2). This is due to the downward trend of coal production in energy generation in Nigeria from the peak period of 790,030 tons in 1956 (CIA, 2015) to 41,610st in 2015. As shown on the table, coal contributes 1369TJ of energy which is the least source of energy in Nigeria. This downward trend in coal consumption can be directly link to the emergence of oil within the same period and the conversion of most engines of power plant/railway from coal to diesel/natural gas. This transition is a welcome development in Nigeria due to the fact that coal being environmentally unfriendly fuel with higher carbon content will produce more GHG emissions than other fossil fuels.

As can be seen on table 3, the natural gas (dry) is the third largest single energy source in the country, contributing about 740,464TJ of energy in Nigeria which is about 30% of all energy consumption in Nigeria, coming only after biomass and the combined energy from liquid fuel source. While the total energy from the biomass is 948,473TJ which does not doubled the energy from the natural gas, but the GHG emissions from the biomass fuel doubled by far more than the emissions emitted by natural gas. Thus more emissions is being released per tera joule in the combustion of biomass than natural gas. This is also true for liquid fuels with 772,488TJ of energy. Thus it can be argued that natural gas in Nigeria is more environmentally friendly fuel than liquid fuels and more than the biomass fuel by a factor of 2 as can be seen on table 3, 1 and 4. This indicates natural gas fuel to be more environmentally friendly than the biomass and liquid fuels. The GHG emissions from natural gas (dry) contribute about 41,540 (Gg CO2) emissions in the country, however, when combined with the emissions arising from the flared and reinjected natural gas, natural gas will be the single biggest contributor of carbon emissions with emissions of about 130,405 (Gg CO2) and second largest emitter of CH4 gas with emissions of about 13 (Gg CH4) as can be seen on table 3, 5 and 6. Thus 45% of all carbon emissions and 30% of all methane emissions from energy sector comes from natural gas, which can be in the form of consumption, flaring or reinjection.

Table 2: Solids Fuels Consumption and GHG Emissions in Nigeria

Sector	**Energy**								
Category	**Fuel combustion activities**								
Sheet	**(CO_2, CH_4 and N_2O from fuel combustion by source categories – Tier 1)**								
	Energy consumption			**CO2**		**CH4**		**N2O**	
	A	B	C	D	E	F	G	H	I
	Consumption	Conversion Factor	Consumption	CO2 Emission Factor	CO2 Emissions	CH4 Emission Factor	CH4 Emissions	N2O Emission Factor	N2O
	(Short Stone)	(TJ/St)	(TJ)	(kg CO2/TJ)	(Gg CO2)	(kg CH4/TJ)	(Gg CH4)	(kg N2O /TJ)	Emissions

									(Gg N2O)
			C=A*B		E=C*D/106		G=C*F/106		I=C*H/106
Solid fuels									
[2]Other Bituminous Coal	41,610	0.0329	1368.969	94600	129.5044674	1	0.001368969	1.5	0.002053454
Total					**129.5044674**		**0.001368969**		**0.002053454**
Source:(2) Country's Watch, 2016; IPCC Guidelines for National Greenhouse Gas Inventories, 2006									

Table 3: Natural Gas Consumption and GHG Emissions in Nigeria

Sector	**Energy**								
Category	**Fuel combustion activities**								
Sheet	**(CO_2, CH_4 and N_2O from fuel combustion by source categories – Tier 1)**								
	A	B	C	D	E	F	G	H	I
	Consumption	Conversion Factor	Consumption	CO2 Emission Factor	CO2 Emissions	CH4 Emission Factor	CH4 Emissions	N2O Emission Factor	N2O Emissions
	(MSCF)	(TJ/MSCF)	(TJ)	(kg CO2/TJ)	(Gg CO2)	(kg CH4/TJ)	(Gg CH4)	(kg N2O /TJ)	(Gg N2O)
			C=A*B		**E=C*D/106**		**G=C*F/106**		**I=C*H/106**
Natural gas									
[1]Natural Gas (Dry)	682,455,000	1.09E-03	740463.675	56100	41540.01217	1	0.740463675	0.1	0.074046368
Total					**41540.01217**		**0.740463675**		**0.074046368**
Source:(1)Department of Petroleum Resources Annual Oil and Gas Report, 2015; IPCC Guidelines for National Greenhouse Gas									

Table 4: Biomass Fuels Consumption and GHG Emissions in Nigeria

Sector	**Energy**								
Category	**Fuel combustion activities**								
Sheet	**(CO_2, CH_4 and N_2O from fuel combustion by source categories – Tier 1)**								
	Energy consumption			**CO2**		**CH4**		**N2O**	
	A	B	C	D	E	F	G	H	I
	Consumption	Conversion Factor	Consumption	CO2 Emission Factor	CO2 Emissions	CH4 Emission Factor	CH4 Emissions	N2O Emission Factor	N2O Emissions
	(Tonnes)	(TJ/T)	(TJ)	(kg CO2/TJ)	(Gg CO2)	(kg CH4/TJ)	(Gg CH4)	(kg N2O /TJ)	(Gg N2O)
			C=A*B		**E=C*D/106**		**G=C*F/106**		**I=C*H/106**

Biomass									
3,4,5,6Wood / Wood Waste	50,148,935.69	0.016	802382.971	112000	89866.89275	30	24.07148913	4	3.209531884
[3,4,5,6]Other Primary Solid Biomass	8,116,101.19	0.018	146089.8214	100000	14608.98214	30	4.382694641	4	0.584359286
Total					**104475.8749**		**28.45418377**		**3.79389117**
Source: (3) Ikuponisi, 2004; (4)Sambo, (2005); (5)Zaku, et al. (2013) and (6)Oladeji, (2014); IPCC Guidelines for National Greenhouse Gas									

Table 5: Fugitive Emissions from Oil and Gas Extraction

Sector	**Energy**								
Category	**Oil and natural gas**								
				CO_2		**CH_4**		**N_2O**	
Sector	**A**	B	C	**D**	**E**	**F**	**G**	**H**	**I**
Name	**Activity**	Conversion Factor[(b)]	Consumption	**Emission Factor**	**Emissions**	**Emission**	**Emissions**	**Emission**	**Emissions**
	(MSCF)	(10^6 m^3/mscf)	(10^6 m^3)	(Gg/10^6 m^3)	**(Gg)**	**Factor**	**(Gg)**	**Factor**	**(Gg)**
			C=A*B		**C=C*D**		**E=C*F**		**G=C*H**
Oil and Natural Gas									
[1]Flaring	**330,933,000**	**2.78E-05**	**9,203**	**1.20E-03**	**1.10E+01**	**7.60E-07**	**6.99E-03**	**2.10E-08**	**1.93E-04**
		Conversion Factor (10^3 m^3/mscf)	Consumption (10^3 m^3)	**Emission Factor Gg/10^3 m^3**					
[1]Reinjection	**743,029,000**	**2.78E-02**	**20,663,636**	**4.30E-03**	**8.89E+04**	**5.90E-07**	**1.22E+01**	**0**	**0.00E+00**
				TOTAL	**8.89E+04**	**TOTAL**	**1.22E+01**	**TOTAL**	**1.93E-04**
Source: (1)Department of Petroleum Resources Annual Oil and Gas Report, 2015; IPCC Guidelines for National Greenhouse Gas Inventories, 2006									

The single largest contributor of greenhouse gas emissions in the energy sector in Nigeria is the biomass. It contribute about 36% of the carbon emissions, 65% of the methane emissions and 88% of all nitrogen oxide emissions in Nigeria as illustrated in table 4 above. This is not surprising giving that biomass is the largest source of fuel in Nigeria, the consumption of biomass stand at 948, 473TJ of energy as can be seen on Table 4 above, this confirms the findings of (EIA, 2015; Sa'ad and Bugaje 2016) that biomass is the largest source of energy in Nigeria. Additionally, biomass contribution to energy supply in Nigeria is more than total energy demand of 125 countries in the world, prominent among which are Morocco, Bulgaria, Libya, Syria, Yemen, Ethiopia, Sudan and South Sudan e.t.c. Being the fuel with largest contribution of GHG emissions, biomass is considered the most environmentally unfriendly

fuel in Nigeria, substituting biomass as source of fuel with natural gas will cut down methane emissions by about two-third, nitrogen oxide emissions by about ninetenth and carbon emissions by one-third. Other environmental benefits of substituting biomass as a source of fuel include; preserving our forest reserve, reducing the rate of desertification and preserving the carbon store by the plant during its growth (Spliethoff, 2010). The combustion of biomass not only increase the amount of GHG emissions but also reduces it greatest storage facility through felling down of trees/forest depletion.

Table 5 above shows the fugitive emissions arising from the extraction of crude oil and natural gas as a result of reinjection and flaring of natural gas. The result indicate that while flaring of natural gas contribute about 11 (Gg Co2) of carbon emissions, reinjection contributes about 88,864 (Gg Co2) of carbon emissions. Additionally, the methane emissions arising from reinjection is the second largest contributor methane emission in Nigeria, coming second to biomass emissions. Thus if new and efficient technology can be used in the extraction of crude oil a lot of GHG emissions can be reduced in Nigeria.

Table 6: Summary of GHG from the Energy Sector

Sector	Energy			
Category	Fuel combustion activities			
Sheet	Energy Consumption	(CO_2, CH_4 and N_2O from fuel combustion by source categories – Tier 1)		
Fuel Types	Tera joule	CO_2	CH_4	N_2O
		E	G	I
	(TJ)	CO_2 Emissions (Gg CO_2)	CH_4 Emissions (Gg CH_4)	N_2OEmissions (Gg N_2O)
Liquid fuels	772,488.37	54,144.24535792	2.31746512	0.46349302
Solid fuels	1,368.97	129.50446740	0.00136897	0.00205345
Natural Gas	740,463.68	41,540.01216750	0.74046368	0.07404637
Biomass	948,472.79	104,475.87489149	28.45418377	3.79389117
Gas Flaring & Reinjection		88,864.68080308	12.19854000	0.00019327
Total	**2,462,793.81**	**289,154.31768739**	**43.71202153**	**4.33367728**

The total energy consumption and GHG emissions attributable to various energy sources in Nigeria is indicated on table 6 and figure 1. It shows that the total energy consumed in Nigeria in 2015 was 2,462,793.81TJ (2.33 quadrillion btu) which makes it the 36th largest consumer of primary energy in the world. It contributes corresponding GHG emissions of 289, 154 (Gg CO2), 44 (Gg CH4) and 4 (Gg N2O).

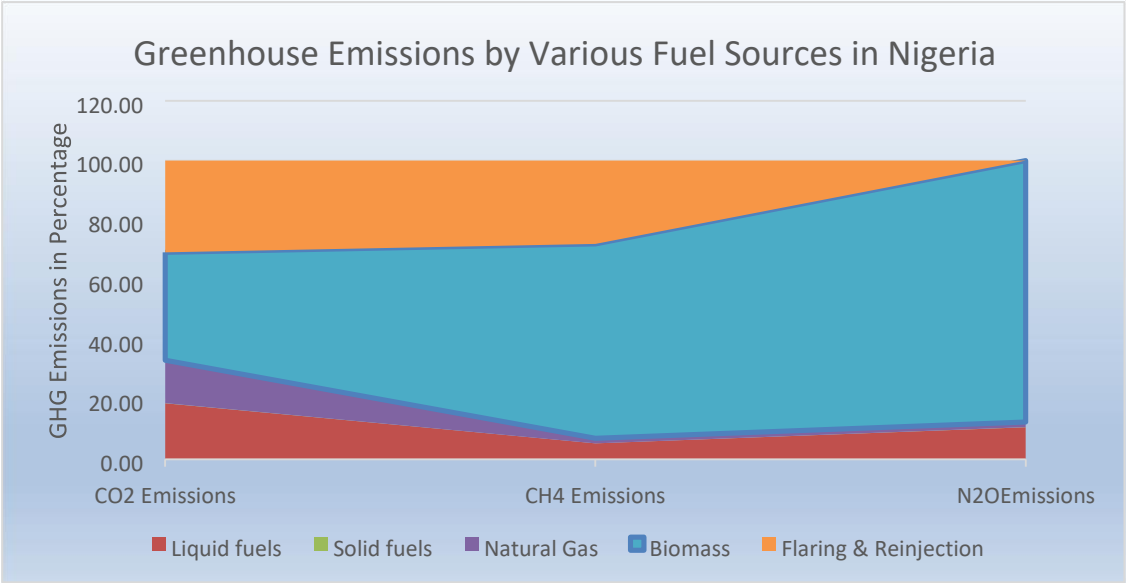

Figure 1: GHG by Fuel Source in Nigeria

Additionally, table 6 and figure 1 shows that biomass is the largest fuel consumed with 948,472.79 TJ of energy being sourced from biomass, hence the largest contributor of GHG emissions in Nigeria. It contributes about 36% of the CO2, 65% of CH4 and 88% of the N2O emissions. This is not surprising as Nigeria was ranked second in the global fuel wood consumption with a global share of 9.2% (United Nation (UN), 2013). Thus biomass can be said to be the least environmental friendly fuel in Nigeria for being the fuel contributing contributes 19% of CO2, 5% CH4 and 11% N2O emissions in the country. The exploration and flaring of natural gas is the second largest contributor of GHG emissions. It contributes 31% of CO2 and 28% of CH4 emissions, this is also not surprising as Nigeria was ranked as the world's fifth-largest gas flaring country, accounting for 8% of the total amount flared globally in 2014 [38`]. The least GHG emissions comes from solid fuels wit 129 Gg CO2), 0.001 (Gg CH4) and 0.002 (Gg N2O). Thus the combined emissions from biomass and production of crude oil/natural gas are responsible for two-third of the carbon emissions, nine-tenth of the methane emissions and about nine-tenth of Nitrogen oxide emissions in the energy sector.

Furthermore, by substituting biomass fuel with a carbon lean fuel such as natural gas, will lead to a reduction of carbon emissions as result biomass combustion by 49%, methane emissions by 97% and Nitrogen oxide by 98%. This would lead to overall reduction of carbon emissions in the energy sector by 18%, methane emissions by 63% and Nitrogen oxide by 85%. Hence, by using more efficient technology in the production of crude oil/natural gas and transitioning from biomass fuel to more environmentally friendly fuel such as natural gas about half of the GHG emissions from the energy sector can be cut in Nigeria.

CONCLUSION AND RECCOMENDATIONS

This study quantify and examine the metabolic flows of energy in Nigeria and its corresponding environmental impact. Some of the major findings are;

The results reveals low energy consumption in Nigeria as compared to its population with consumption standing at 2,462,793.81TJ (2.33 quadrillion Btu). This makes Nigeria the 36th

largest consumer of energy in the world with Malaysia and Algeria consuming more energy than Nigeria. Notwithstanding, the corresponding GHG emissions as compared to the consumption of primary energy is high, it currently stand at 289, 154 (Gg CO2), 44 (Gg CH4) and 4 (Gg N2O), which is equivalent to the total CO2 emissions from all sectors in Malaysia and twice the total emissions from Algeria and 3 times greater than the total emissions from Chile. Additionally, the single largest contributor of greenhouse gas emissions in the energy sector in Nigeria is the biomass. It contribute about 36% of the carbon emissions, 65% of the methane emissions and 88% of all nitrogen oxide emissions in Nigeria. This is not surprising giving that biomass is the largest consumed fuel in Nigeria. Additionally, biomass contribution to energy supply in Nigeria is more than total energy demand in 125 countries of the world, prominent among which are Morocco, Bulgaria, Libya, Syria, Yemen, Ethiopia, Sudan and South Sudan e.t.c.

The three largest energy sources in the Nigeria are the biomass, liquid fuels and natural gas contributing about 36%, 31% and 30% share of energy respectively. While the total energy from the biomass does not doubled the energy from the natural gas, but the GHG emissions from the biomass fuel is twice greater than the emissions emitted by natural gas. Thus more emissions is being released per terajoules in the combustion of biomass than natural gas. This is also true for liquid fuels. Thus it can be said that natural gas in Nigeria is more environmentally friendly fuel than liquid fuels and more than the biomass fuel by a factor of 2. The order of friendliness of fuels in Nigeria decrease from natural gas to liquid fuels and finally to biomass. Thus, biomass is considered the most environmentally unfriendly fuel in Nigeria.

Moreover, the findings reveals that exploration and flaring of natural gas is the second largest contributor of GHG emissions. Thus the combined emissions from biomass and production of crude oil/natural gas are responsible for two-third of the carbon emissions, nine-tenth of the methane emissions and about nine-tenth of Nitrogen oxide emissions in Nigeria. Furthermore, by substituting biomass fuel with a carbon lean fuel such as natural gas, would lead to overall reduction of carbon emissions in Nigeria by 18%, methane emissions by 63% and Nitrogen oxide by 85%.

Since, the combustion of biomass and inefficient exploration of oil/gas appears to be the greatest contributor of GHG emissions in Nigeria, the paper suggest some sustainable options that would lead to the reduction of GHG emissions. These options include the use of more efficient technology in the exploration of oil/gas and the transitioning from biomass fuel to more environmentally friendly fuel such as natural gas.

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USING GESTURES TO INTERACT WITH HOME AUTOMATION SYSTEMS: A SOCIO-TECHNICAL STUDY ON MOTION CAPTURE TECHNOLOGIES FOR SMART HOMES

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Keywords: Home Automation, Gesture Control, Usability, Pervasive Computing

Abstract

Homes and working spaces are considered significant contributors to the top percentage of energy consumption and carbon emissions worldwide (GeSI Report, 2017). Previous studies in the field of home- and building automation have demonstrated the sustainability gain brought by smart home solutions, in terms of energy-efficiency, economic savings, and enhanced living and working conditions. A major barrier, however, to the adoption of these solutions is the complexity and limited usability of user interfaces. In addition, various modes of interactions for the control and automation of residential environments are an emerging area of study within Human-Computer Interaction. As a response to these challenges, this study investigates the use of gestures as a natural way of controlling and interacting with home automation systems. Using the available motion capture technology, a gesture dictionary will be defined as a set of meaning actions in free-form and in-air movements. A usability test will be conducted to measure the resulting socio-technical aspects. Lastly, the study will present the analysis and effects of gestures control for a higher up-take of smart home solutions towards designing and maintaining buildings of the future that are both user-centric and resource efficient to reduce our overall carbon footprint.

INTRODUCTION

In an article published by Eurostat regarding energy trends from data collected June of 2017, households comprise 25.4% of the final energy consumption, one of the dominant categories together with transport (33.1%), and industry (25.3%) within the European Economic region [1]. In addition, buildings, both homes and working spaces, are culpable for the 36% of the total carbon emissions in Europe [2]. The European Commission is convinced that by using commercially available building automation technologies, possible reductions to energy consumption can be up to 6%, and 5% for the total carbon emissions [2]. Through its policies, initiatives, and research activities, the European Union pushes its citizens to use energy more efficiently - to lower their utility bills, reduce their reliance on external suppliers of oil and gas, and help protect the environment.

The Global e-Sustainability Initiative (GeSI) suggests in its #Smarter2030 Report that ICT in households and buildings will increase comfort and reduce energy and water bills. The report adds that smart building solutions could cut up to 2.0Gt of carbon emissions from the housing sector, reducing energy consumption by 5 billion MWh, and creating revenue opportunities of another $260 billion [3]. The future of smart buildings relies on the concept of insight and control, from smart metering that enhances people's awareness of their energy and resource

consumption to enabling users to interact with these technologies remotely and automatically. These solutions will lead to strong sustainability impacts such energy and resource efficiency, improved processes and automation, and enhance living conditions and productivity.

Home automation technologies have been commercially available for a couple of years now, these solutions repeatedly faced market failures. Amid all the benefits, low usability can be seen as one of the prominent reasons for the high level of reluctance from customers to invest in home automation systems (HAS) [4]. Other factors include high investment cost, lack of flexibility and scalability, and the variety of individual products that are not easily interoperable. However, the user interface and control are often reported to be the most unusable product due to its poor design and complex features which result in home automation technologies being inaccessible to a wide range of non-technical users [4].

As a response to these challenges, this research aims to investigate whether a natural mode of interaction would entice users towards adopting home automation systems. This investigation looks into gesture control as an intuitive way of interacting with home automation systems. A survey of motion capture sensors and its applications will be done to evaluate suitable technologies. Meaningful actions will then be defined as gestures in the context of HAS interaction and control. Lastly, a usability study will be conducted to measure the level of sociotechnical aspects such as acceptability, ease of use, and gesture anthropology. The need to pursue this study arises from the need to improve the up-take of HAS thus maximizing its potentials to address economic, environmental, and usability issues.

REVIEW OF RELATED WORKS

This chapter will be divided into three sections dealing with the following topics: (a) home automation systems, (b) motion capture technologies, and (c) gesture interaction and usability. Each section will discuss previous studies, applications, and works that are either directly or indirectly but substantially related to this work.

Home Automation Systems

Previous studies in Home Automation and Smart Homes have various definitions of these common buzz words. David, et. al (2002) defines it as “the integration of technologies and services, applied to homes, flats, apartments, houses and small buildings with the purpose of automating them and obtaining and increasing safety and security, comfort, communication, and technical management” [5]. In another study Malcolm (2001) put it as “one where smart technologies are installed and where those technologies facilitate automatic or user-initiated communication, involving a range of appliances, sensors, actuators and switches” [6]. Martinez (2017) also referred to it as a derivative of Building Automation (BA) which is specifically implemented in homes and residential spaces [7]. These are the working definitions that will be used in the context of this research.

In the following chapters, the term Home Automation Systems (HAS) will be used to define the collective idea and concepts of home automation, smart homes, and domotics, which were loosely referred to in the literature and other related works. In addition, Smart Home Technologies will be the working term for all technologies, such as sensors, actuators, and similar devices that are used and integrated towards developing and implementing HAS.

Motion Capture Technology

The release of the LEAP Motion Controller in 2013 opened new frontiers for gesture technologies. While the industry and tech enthusiasts differ in opinion on how useful the highly publicized device was, the sale of the product – along with the new generation XBOX Kinect sensor by Microsoft, marked a step forward for commercial gestural interface use [8]. We are interested with gestural interfaces for several reasons. Advances in technology have made gesture recognition more feasible and affordable in terms of low-cost and efficient microcontrollers, enhanced machine vision software, and state of the art 3D cameras and depth sensors [8].

Gesture control technologies or gestural interfaces can be categories to either perceptual or nonperceptual technologies [9][10]. Like how Karam & Schraefel put it, perceptual technologies are those which enables gestures to be recognized without requiring any physical contact with an input device or with any physical objects, allowing the user to communicate gesture without having to wear, hold or make physical contact with any intermediate devices [9]. Non-perceptual technologies, on the other hand, are those that involves the use of artifacts such as a glove, pen, or mouse, and requires physical contact to transmit spatial or temporal information as input.

For the purpose of this study, we focus on perceptual technologies, such as the Microsoft Kinect, in terms of its ability to enable gesture recognition without the need for physical contact. Nonperceptual technologies will still be mentioned in related works as these are studied and used along-side the Microsoft Kinect. Thus, while several studies have investigated models and methods in meaningful gestures on screens, gloves, pens, and other non-perceptual technologies that require physical contact, this study focuses on defining a set of "in-air" gestures with attention to making a natural and intuitive way of interacting with home automation systems. Although this is not an exhaustive look at literatures regarding Microsoft KINECT and the technology behind it, the survey or related works provides a practical mean to understand how the device work, and its application in research.

With the invention of Microsoft Kinect sensor, high-resolution depth and visual (RGB) sensing has become more available for widespread use [11]. The complimentary nature of the depth and visual information provided by the sensor opens up new frontiers to solve fundamental problems in machine vision. Though originally perceived to revolutionized entertainment as a control-free interface for XBOX, Kinect's impact has extended far beyond the gaming industry [5]. Many researchers have utilized the device to develop creative ways to interact with machines and perform different tasks – Microsoft calls this the "Kinect Effect." In 2012, the tech giant released the first version of the Kinect Software Development Kit (SDK) for Windows, which undoubtedly amplified the Kinect Effect to reach more practitioners and developers from the fields of computer science, electronics engineering and robotics, thus transforming human-computer interaction in multiple industries [12]. The following is a survey of studies published on Microsoft Kinect technology evaluation and its applications.

The Kinect found its way outside the living room to the other places inside the house. Panger [13] studied the problem of people who want to flip through recipe books, change music, or set a kitchen timer even with hands messy from cooking or baking. Another application that

uses Kinect is the Ambient Wall [14], a smart home system that allows users to control the television, air conditioning, and others through an interface projected on a wall. Hands-Up [15] uses the device with a projected user interface on the ceiling surface, where users lying in bed put their hands up to control devices. You, et. al. [16] integrated Kinect with and Arduino creating an immersive ambient entertaining environment in automating parties. The system is responsive and sensitive to human activity such as gestures, body movement and facial expressions.

Using Kinect as an assistive technology at home was also popular especially in terms of activity monitoring, tele-rehabilitation, and elderly care. Lin, et. al. [17] used the high-resolution RGB and depth images taken using the Kinect and applied continued deep learning models in neural networks to detect abnormal events to help users avoid injuries from falling. To promote healthier living at home, Zhao & Lun [18] developed a user activity tracking system using Kinect with sensor inputs and fitness bands for health feedback. The system continuously monitors users and detect bad postures. Logs can be accessed via mobile devices to see their progress.

In a more medical application, Blumrosen, et. al. [19] used the Kinect as a non-wearable sensor to track human activity at home. They extracted Kinect Signatures to differentiate patients for tele-rehabilitation and kinematics therapy. Kinect was also used as a smart home aide to people with disabilities, the differently-abled, and patients with specific needs, for applications such as controlling appliances [20] and interpreting sign language as commands [21].

As presented in this section, the survey of related works and published literature regarding the research viability of such devices proved exciting potential for the Microsoft Kinect as a gesture control technology suitable for the implementation of this study. Thus, while several studies have showed the potential of motion capture sensors outside of gaming and entertainment, in areas such as tele-rehabilitation, aid for the elderly and people-with-disabilities, and digital interactions, this study investigates on the use of the Microsoft Kinect to interact with home automation systems to attain a higher uptake for smart home technologies towards promoting sustainability.

Gesture Interaction & Socio-Technical Aspects

The use of gestural interaction, being frequently used in everyday social life, is considered intuitive in human communication. When addressing the naturalness of interaction (ie. intuitive, easy to learn) it is indispensable to consider social and cultural aspects of a target audience when defining a gestural vocabulary - thus meaningful gestures that do feel natural, intuitive, and easy to learn.

Developers and researchers try to provide solutions to users through complex computational means, as seen with improved accuracy, efficiency, and robustness in the case of Microsoft Kinect, aside from the technical aspects [12][22][23] however, the social sphere needs to be considered as well. With this in mind, Correia, et. al. [10] proposed a framework to identify and discuss the challenges of different forms of interaction with technology considering sociotechnical aspects in an integrated manner. The framework consists of the main dimensions: home automation systems, gesture interaction, and human. The concentric organization of these three suggests their interdependency in a triadic relationship [10]. And

as shown in Figure 1., each aspect is represented by a dashed ellipse and has interactions with the three dimensions.

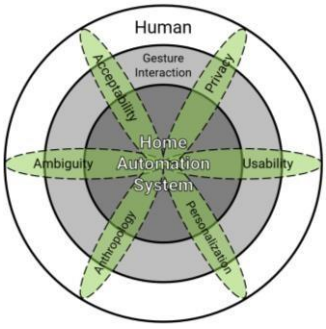


Figure 1. Framework of socio-technical aspects of gestural interaction

Therefore, while several studies have looked into reliability, accuracy, and efficiency in using the Microsoft Kinect for gesture recognition, this study will conduct a socio-technical study under three specific aspects to attain a level of acceptability, ease of use, and gesture anthropology and better understand the relation of gesture control and home automation systems.

- *Acceptability* – level of user's positive response towards a new technology or innovation. This aspect will be guided by the Technology acceptance model (TAM) proposed by Davis, et. al [24]. Factors such as Perceived usefulness (PU) and Perceived ease-of-use (PEOU) will be measured to come up with the level of acceptability.
- *Usability or General ease-of-use* – measure of learnability, memorability, errors, satisfaction and overall comfort of the user towards the technology. These main topics were suggested by Nielsen [25] to understand how usability interplays with gestural interaction.
- *Culturability or Gesture Anthropology* – suggestive measure of naturalness or intrusiveness of interaction with the home automation system for people coming from different cultural or ethnological background. Researchers are still trying to understand how the gestures are influenced by culture [10]. Although this detail might seem irrelevant for the definition of gestures, it might very well influence whether a certain gesture is considered appropriate in a certain cultural context.

RESEARCH FRAMEWORK AND METHODOLOGY

A workflow methodology as shown in Figure 2 will be followed for this study. This was based on the Design Science research which is a prescriptive knowledge framework that aims to develop useful artifacts guided by three closely related cycles [26]. The relevance cycle initiates design science research with an application context that not only provides the requirements for the research as inputs but also defines acceptance criteria for the ultimate evaluation of the research results. The rigor cycle provides past knowledge to the research project to ensure its innovation. The central design cycle iterates between the core activities of building and evaluating the design artifacts and processes of the research – for the purpose

of this work, action research methodology will take over the design cycle towards implementing the artifact.

The workflow will have five stages where components of the design science research are incorporated. First, problem identification which include literature review corresponds to knowledge-base and grounding from the Rigor Cycle. Requirement Definition (from Relevance Cycle) will include technology survey and gesture definition while Artifact Development (Design Cycle) encompassed proof-of-concept and prototyping. To complete the Design Cycle, we move to Observation & Feedback with the usability testing; and Evaluation with the analysis and discussion towards a coherent conclusion of the research.

RESEARCH METHODS

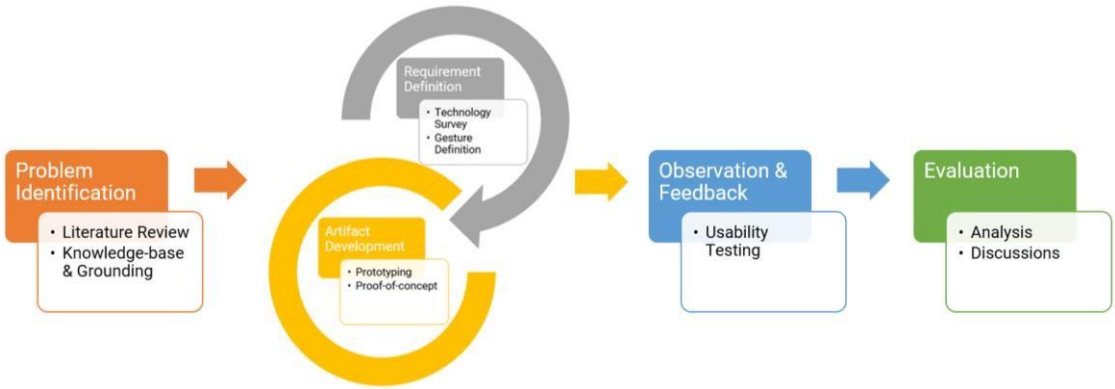


Figure 2. Workflow methodology based on design science framework

This chapter will discuss stages 2 to 4 of the research workflow. As such, it will be further divided into three other sections: (a) Microsoft Kinect & Artifact development, (b) Gesture Recognition & Machine Learning, and (c) Demo & Testing. This section will tackle topics regarding the technical implementation done towards the purse of the research goals.

Microsoft Kinect & Artifact Development

Figure 3 below describes how the perceived system would work. The gesture will be taken in by the Kinect sensor, the input feed will go into the gesture recognition algorithms for detection and labelling, then controls will be sent out to the home automation server through a web socket. This then will control the corresponding smart home device as commanded by the gesture.

The Microsoft Kinect offers high-quality skeletal tracking and recognition. The sensor consists of a color camera (RGB), depth sensor with infrared (IR) camera and projector, and a built it microphone array. It can track up to six bodies simultaneously with 25 skeletal joints each, and three recognized hand states: open (palms out), closed (clenched fist), and lasso (2 fingers). The Kinect Windows SDK was used to develop C# software for the use of this study. In addition, the Kinect Studio v2.0, and Visual Gesture Builder were utilized for motion capture and labelling. Home Assistant and FHEM were used as open-source HAS platform and server while HomeMatic actuators were integrated for the smart home devices.

Machine Learning & Gesture Recognition

The gesture recognition process followed the Machine Learning approach that is divided into six steps for all nine gestures presented in Figure 4 and Table 1. First was (1) data acquisition with gesture recording using the Kinect Studio v2.0 then each raw input file in xref format was ran through (2) pre-processing for compression and optimization. Now using the Visual Gesture Builder, (3) features were extracted after proper labelling, (4) training and test sets were separated with training sets were put into (5) post processing with two active algorithms: AdaBoost Trigger (discrete gestures) and RFRP Progress (continuous gestures), then lastly creation of the (6) classification model.

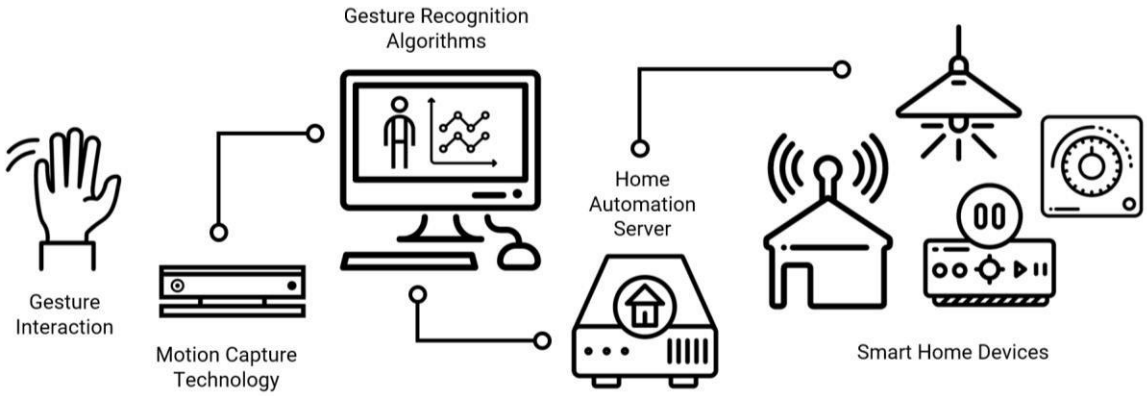


Figure 3. System architecture diagram for gesture interaction for HAS

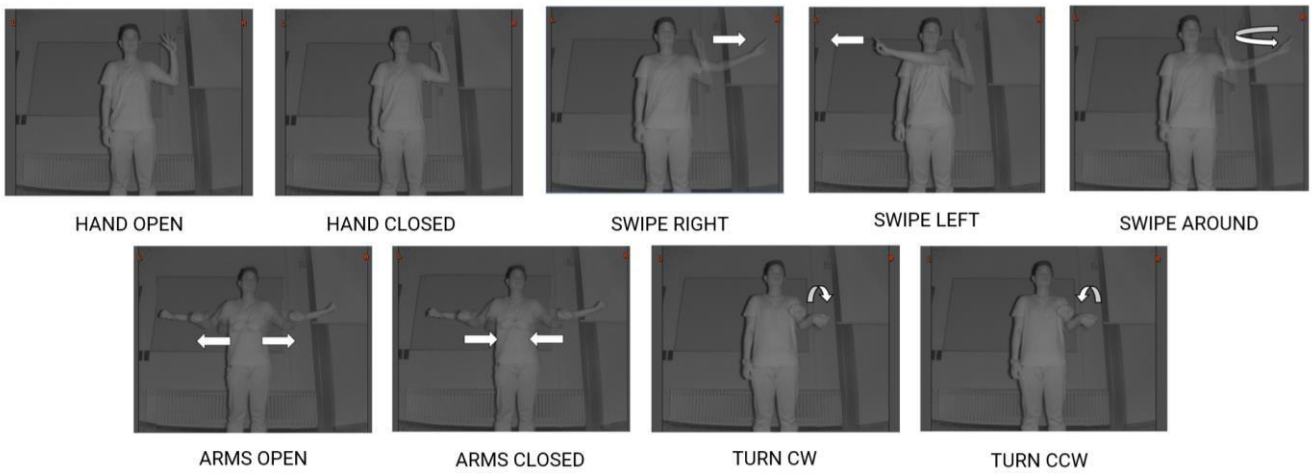


Figure 4. Gesture dictionary visualized with Microsoft Kinect

Table 1. Gesture Dictionary for HAS

Gesture	Description	Command
HAND OPEN	Open hand near the head	Turn on the lights
HAND CLOSED	Clenched fist near the head	Turn off the lights
SWIPE RIGHT	Lasso (2 fingers) near the head, swiping to the right	Next song/ item
SWIPE LEFT	Lasso (2 fingers) near the head, swiping to the left	Previous song/ item
ARMS OPEN	Both fists clenched in front of the body, extending from center outwards	Open curtains
ARMS CLOSED	Both fists clenched, abdominal level away from the boy, moving towards the center	Close curtains
TURN CW	Clenched fist at arm level, turn wrist clockwise (to the right)	Heater value up
TURN CCW	Clenched fist at arm level, turn wrist counter-clockwise (to the left)	Heater value down
SWIPE AROUND	Lasso (2 fingers) near the head, make a circular movement horizontally	Toggle everything

Demo & Testing

After the prototype was ready for demo, a testing schedule was prepared, and prospective participants were invited. To help look into capturability and gesture anthropology, a mix of local and international students were invited to participate in the demo and testing. In the end, 32 students, from 12 countries, volunteered to participate. The participants were provided with an informed consent form for minimal risk (classroom activities/ projects involving human participants) to ensure that their health, safety, and protection are assured in the activity. It also ensures that their information will be protected under the "General Data Protection Regulation" (GDPR EU 2016/679) of the European Union.

For the demo, each participant was asked to interact with the motion capture prototype, answer the questions regarding usability, and provide feedback regarding their experience of the technology. For this, a structured questionnaire was prepared to observe three socio-technical aspects to help us understand gesture interactions for home automation systems. The questions are formulated to be Likert items with under three Likert scales corresponding to acceptability, ease-of-use, and culturability. Table 2 presents the Likert items and their descriptions.

After the demo run, the participants were asked for any clarifications and if they have any suggestion to improve the study. All data were then encoded and tabulated for further analysis.

Table 2. Likert Items for the Socio-Technical Study

NO.	ITEM	HEURISTICS	ASPECT
A1	Gesture control will improve my overall experience with smart homes.	Perceived usefulness	Acceptability
A2	Gesture control will make interacting with smart homes easier.	Perceived ease-of-use	Acceptability
A3	I will easily get used to smart home interactions with the help of gestures.	Attitude towards using the technology	Acceptability
A4	Gestures will be a typical way of interacting with technology in the future.	Behavior towards intention of use	Acceptability
U1	The gestures are generally easy to remember.	Memorability	Usability
U2	Most gestures are easy to learn because to correspond well with the commands.	Learnability	Usability
U3	The gestures are generally very complex and complicated to perform.	Efficiency	Usability
U4	It is easy to make errors or mistakes with the current set of gestures.	Error	Usability
U5	I am generally satisfied with the gestures used for smart home interaction.	Satisfaction	Usability
U6	Most gestures are straining to the arms and hands.	Comfort	Usability
C1	Using gesture is a natural way of interacting with smart home technologies.	Intuitiveness	Culturability
C2	My culture is known to use (hand/body) gestures as part of everyday communications.	Gesture use	Culturability
C3	These gestures reflect possible interactions of people from where I am from.	Gesture anthropology	Culturability
C4	My cultural background is known to be very accepting of new technologies/ innovations.	Openness to innovation	Culturability
S1	Compared to other media (voice command and remote controls), I am open to using gestures to interact with smart homes.	Comparison to other available mode of interactions	(Summary/ Debriefing)
S2	I would buy (or invest to) smart home devices to control my home.	Perceived investment	(Summary/ Debriefing)
S3	I would but (or invest to) gesture technologies to interact with my smart home.	Perceived investment	(Summary/ Debriefing)

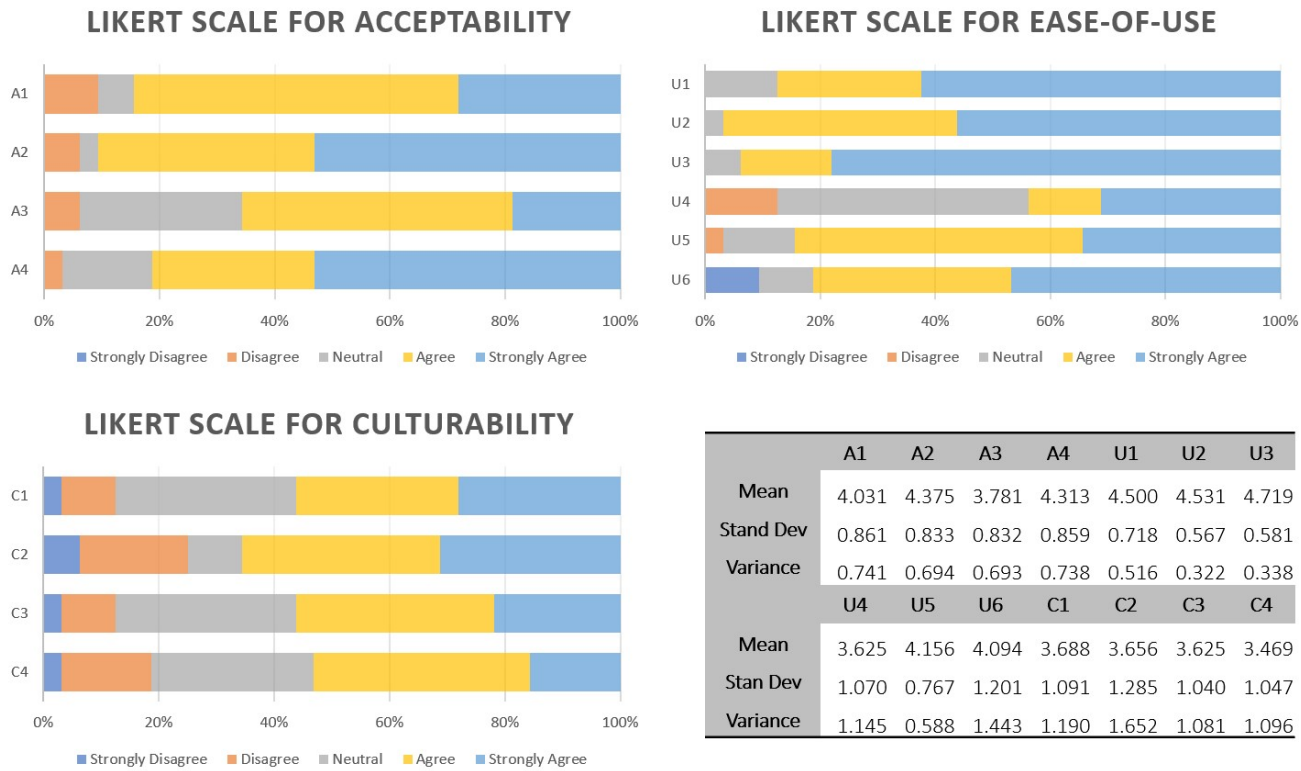
RESULTS AND FINDINGS

There was a total of 32 participants for the demo and testing, of which 87.5% are aged 18-26, and 9.4% aged 27-35 years old. Regarding the participants' current living situation: 65.6% are living with roommates or in shared flats, 21.9% live by themselves, and 12.5% live with their families. It is also significant to mention that even only 31.3% of the participants have access to smart home devices, from 68.8% who does not, 95.7% of which are interested in such devices, the remaining 4.3% are just not interested or rather highly critical.

As shown in Figure 5, we can pinpoint the Likert item that performed best for each aspect. A2 that suggests perceived ease-of-use has the highest mean of 4.375 for acceptability. U3 which is about efficiency got 4.71875, highest for usability aspect. And C2 which talks about gesture use got 3.656, for the capturability aspect. We can also compute for the global mean for each Likert scale that corresponds to the suggestive level of each socio-technical aspect.

Acceptability garnered a score of 4.125, ease-of-use with 4.271, and culturability with 3.609, out of 5.0.

Aside from descriptive analysis, we can also apply inferential statistics to look into the data gathered from the demo/ testing. As a special case, we put together data for participants coming from the same country. There are seven (7) data points each for Germany, Spain, France. For this, analysis of variance (ANOVA) will be applied to see if the hypothesis H_0: "Cultural background does not relate or affect opinion regarding gesture interactions for smart homes," can be denied.



	A1	A2	A3	A4	U1	U2	U3
Mean	4.031	4.375	3.781	4.313	4.500	4.531	4.719
Stand Dev	0.861	0.833	0.832	0.859	0.718	0.567	0.581
Variance	0.741	0.694	0.693	0.738	0.516	0.322	0.338
	U4	U5	U6	C1	C2	C3	C4
Mean	3.625	4.156	4.094	3.688	3.656	3.625	3.469
Stan Dev	1.070	0.767	1.201	1.091	1.285	1.040	1.047
Variance	1.145	0.588	1.443	1.190	1.652	1.081	1.096

Figure 5. Results of the three socio-technical aspects in Likert scale

ANOVA is a collection of statistical models and their associated procedures used to analyze the differences among group means. The total variation or sum of squares, variation within the group, variation between the group, and degrees of freedom are computed to calculate for an F value that will be used for an F-test along the F-distribution curve. As a standard, we choose an F-critical point as a function of the degrees of freedom which is F-critical (2,18) for 10% = 2.62. Comparing all F-values derived from all the 17 Likert items, no values were ≥ F-critical, thus the null hypothesis H_0 is not rejected.

Lastly, we compute for Cronbach's Alpha (or coefficient alpha) which is a measure of internal consistency or how closely related a set of items are as a group to have an idea whether the Likert items play consistently in the questionnaire as whole. For sets with more than 10 items, an alpha value greater 0.70 displays a highly consistent and well sort out data. Given the 17 Likert items in the questionnaire, we calculated a Cronbach's Alpha value of 0.85.

DISCUSSIONS

In studying gestural interaction for technologies such as home automation systems, it is important to not only look into technical issues such as accuracy, efficiency and robustness, but also to socio-technical aspects such as acceptability, ease-of-use, and culturabilty. The positive feedbacks coming from volunteer participants help shed a light to better understand gestures and motion capture technologies for the control of smart home devices.

With participants mostly from the young adult generation which are seen as very technologically adept and the would-be homemakers in the near future, the realization of smart homes into everyday life is far from imagination. The acceptance level is relatively agreeable, 4.125 out of 5.0 with adopting the perceived usefulness of this technology. Under the usability aspect, heuristics such as learnability, memorability, and efficiency for the gesture dictionary, performed well with scores all more than 4.50, thus suggests naturalness and intuitiveness. Culturability or gesture anthropology however is a field that needs more investigation. With the ANOVA conducted for all Likert items, the null hypothesis which proposed that cultural difference does not relate to gesture interactions opinion was not rejected brought by values lower that the Fcritical (2,18).

CONCLUSION

Indeed, the power over living a more sustainable lifestyle is in our hands. This study implemented a proposed home automation system using Microsoft Kinect as a prospective motion capture sensor for the specific context of the research. A gesture dictionary was also defined as meaning gestures with corresponding control commands for smart home devices. These gestures were tested and demonstration for the socio-technical study were aspects such as acceptability, easeof-use, and culturability were measured for the sample population. A positive feedback from the heuristics suggests that gesture interactions for home automation systems are indeed categorically natural and intuitive. The study then responds to the challenge of improving the uptake of HAS thus maximizing its potentials towards designing and maintaining buildings of the future that are both user-centric and resource efficient to reduce our overall carbon footprint.

ACKNOWLEDGEMENT

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Sustainability and People

THE LONG-TERM POTENTIAL OF CONSTRUCTING INSULATED CONCRETE FORMWORK DWELLINGS IN COMPARISON TO USING TRADITIONAL MASONRY

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Keywords: Insulating, Concrete, Formwork, Dwelling

Abstract

Insulated Concrete Formwork is an uncommon method of construction which is rapidly gaining popularity in other European nations, offering multiple long-term benefits in regards to energy efficiency and speed of erection. The method was developed in the 1970's and patented by 'Isorast' who have progressively improved on the system to satisfy the best worldwide standards. The more common method of constructing a dwelling is to use traditional masonry which has been widely used since the 1700's with a mason laying bricks/blocks bonded with a mortar to construct the external walls. Within the UK there are over 23 million homes (Office for National Statistics, 2017), over half of which will have been constructed using traditional masonry, considering the vast improvements in technology in and around the construction industry over the past decade it is an ideal time to scrutinize the traditional method and conclude whether insulated concrete formwork would be a valid improvement. The primary aim of this study is to research how well dwellings constructed using insulating concrete formwork could perform in practice and the possible hurdles as to why the approach is often avoided on larger scale developments with some UK housing associations neglecting the method entirely. The research shall be conducted via a combination of questionnaires, desktop studies and company enquiries to ensure a sufficient quantity of results that can be thoroughly examined. The methodology of this research paper was developed on the basis of gaining feedback and experiences of industry professionals during their careers. Individuals will be requested to provide information regarding the residential sector, ICF construction and traditional masonry. The questionnaire survey will establish an idea of what the respondents prioritise within construction and their opinions on various methods.

INTRODUCTION

Currently, the condition of the UK housing market has been described as "broken" (Financial Times, 2017) first-time buyers and those who are renting are struggling with the increasingly unaffordable prices throughout the United Kingdom. Many believe developers are rushing to erect homes and maximise profit returns compromising the quality of the final product, consequently those with the intentions to relocate often opt to the self-build route. This path can be beneficial entrusting the lead party with the freedom to design their own home to higher standards than those usually exhibited by larger scale developers. The average home within Europe, and particularly the UK, is not conducive to the sustainable living standards that are required by modern environmental ideals, as necessitated by the advent of climate change (Pan

& Garmston, 2012). Good practice in house building can only be achieved through the collaboration of many parties through the process of design, construction, assessment and commissioning.

The global construction industry is under great pressure to minimise build times and maximise the performance capabilities of new structures. New technologies are frequently emerging in the modern era, offering improvements to production efficiency, environmental impact and customer satisfaction. A prominent example could be the implementation of BIM (Building Information Modelling) within the industry, this involves the use of advanced modelling software and is considered as an evolution of computer-aided design (CAD). BIM models are parametric meaning each element of the design is linked so any alterations affect all parts of the overall design, they typically contain informational layers that provide data on pricing, sourcing and energy usage (Micah Isset, 2015). The widespread adoption of BIM systems began in the last decade and users are already reaping the benefits from its efficiency and improvements to productivity. Analysing the swift rate at which practices adapted to the new technology, would a variation in the standard building method of houses be too large of a hurdle for the industry to tackle.

Traditional Masonry is one of the oldest building methods available but still remains extremely popular throughout the residential sector. Earth burnt to form bricks, is a technique dating from Roman times, but brickwork earlier than 1700 is rare in the UK (John and Nicola Ashurst, 2003). This is due to the brickwork structurally failing, often result of being mistreated or poorly maintained. The methods popularity could be result of the high volume of qualified bricklayers within the UK, who will have completed the tailored courses. The latest employment figures from the Office for National Statistics showed the sector was the secondbiggest job creator in 2015 and that by December there were 2.2m jobs in construction in the UK (The Guardian, 2016). Research has indicated that while houses built today using the more traditional methods contain high levels of insulation, double glazed windows and highly efficient heating systems they often do not meet the required standards in practice (Understanding Gap between Designed and Real Performance, Leeds Metropolitan University (2007).

Insulating Concrete Formwork is a method gaining popularity in other European nations; otherwise known as permanently insulated formwork it offers performance levels significantly better than that of more traditional methods. As with masonry, there are various systems available on the market, all offering a selection of benefits. The majority of ICF system manufacturers pride themselves in the highly efficient homes they provide with numerous projects being nominated for national awards such as the Eco House, Glasgow designed by Maclean Architects and incorporating a Wallform 313 system. Considering the vast amount of advocates of the system, could ICF dwellings have the potential to be incorporated more frequently within the UK as an improvement on the more traditional method?

Comparative Analysis of Houses Built from Insulating Concrete Formwork

Daniela Mackova, Marcela Spisakova (2015)

The following case study analyses the use of modern methods of construction (MMC) in house building, within the study a house is modelled in two variants of ICF (Insulated Concrete Formwork) and a variant of bricks. The two selected ICF systems reviewed in this article are Durisol & Medmax, chosen because of their high performance capabilities and contrasting production processes.

Durisol units are formed from using cement-bonded wood fibre material. Composed of a specially graded recycled waste wood, it is initially chipped into wood fibre and then mineralized and bonded together. Durisol cement-bonded wood fibre insulated concrete forms are porous, lightweight and very durable. They do not rot nor decay, they contain no plastic, foams or polystyrene. Durisol enables easy compliance with UK building regulations right through to achieving the high standards of Passivhaus (Durisol UK, 2017).

The Medmax block system consists of two wall units connected by plastic couplings into a block up on site. The blocks are connected to each other with dry connection by cross-latch. It creates a compact concrete wall, without thermal bridges and with insulation on each side.
Building blocks are accurate and light, so it is not necessary to have lifting equipment on site (Cemex UK, 2017).

The masonry aspect of this case is Porotherm, a precision engineered modern clay block walling system. A unique interlocking design rules out the need for mortar in the vertical joints and consistent manufacturing quality allows for true 1mm bed joints. Used successfully for decades across Europe, and now well-established as a building solution for UK working conditions, Porotherm can be used in load-bearing and nonload-bearing applications and is ideal for dwelling construction.

The subject of the study is house (Figure. 1) modelled in mentioned three construction variants.

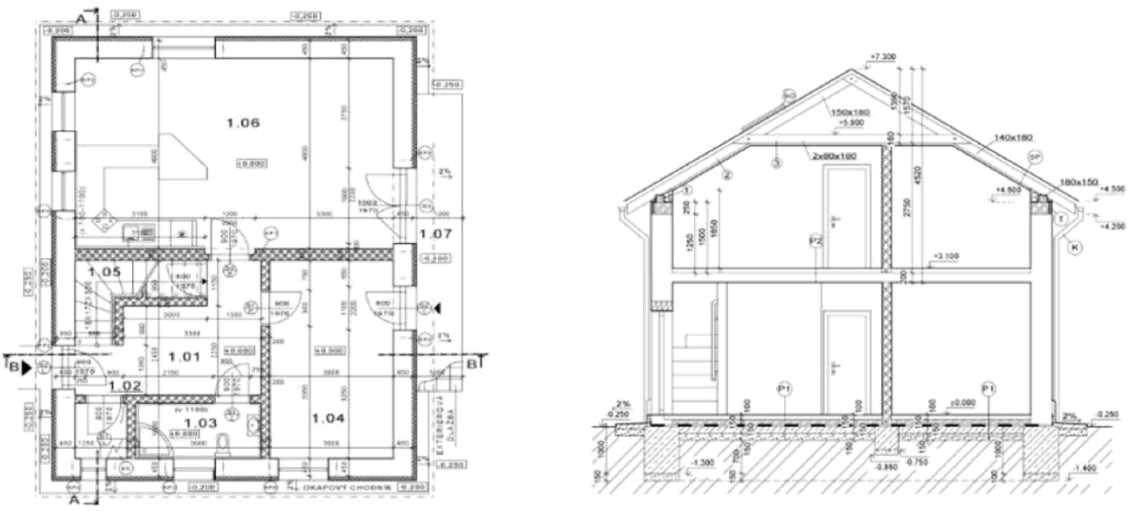


Figure 1: Proposed Floor Plan & Section B-B [Not to Scale]

In accordance to these plans, the selected objectives were quantified in a multicriteria optimisation process. Refer to (Table. 1) for the initial results of the case study.

Table 1: Quantification of multicriteria objectives

House Variant	Objective		
	Construction Cost [£]	Heating Cost [£/Year]	Floor Area [m²]
Durisol	60,047	454	145
Medmax	63,432	421	147
Porotherm	66,231	459	134

Based on the collected results it can be concluded that the Durisol system is the optimal approach from the variants modelled within the study regarding total costs. However, the Medmax system presents the lowest cost annually in relation to heating the building. It must be acknowledged however, that this study omits build-time from the pursued objectives which in other scenarios may instead be of higher priority.

The article presents a partial research result of project VEGA – 1/0677/14 “Research of construction efficiency improvement through MMC technologies”.

Insulating Concrete Formwork, A Guide to use and Application

MPA – The Concrete Centre (2009)

This guide reiterates the principle that Insulating Concrete Formwork is a simple but effective construction technology. The document provides a brief overview of the typical ICF system along with useful technical information.

As well as confirming that ICF is flexible enough to cope with a huge variety of design possibilities and easily exceeds the energy efficiency requirements of Part L of the Building Regulations, the document gives guidance to what architects need to know about the system.

In regards to mortgaging a property it reads, all mortgage lenders, insurance companies and planning authorities accept ICF construction, with some using a BBA certification as a prerequirement to acceptance of non-standard forms of construction, including, in some cases, ICF.

BRE Green Guide

The first edition of The Green Guide series in 1996 aimed to provide a simple 'green guide' to the environmental impacts of building materials which was easy-to-use and soundly based on numerical data. The guide is part of BREEAM (BRE Environmental Assessment Method) accredited rating scheme for buildings.

Materials and components are arranged on an elemental basis so that designers and specifiers can compare and select from comparable systems or materials as they compile their

specification for a project; the data is presented as an A+ to E ranking system. An A+ rating represents the best environmental performance/least environmental impact and E therefore signifying the worst environmental performance/largest environmental impact.

Refer to (Figure. 2) where the various ratings of ICF external wall systems have been quantified along with those of blockwork cavity walls.

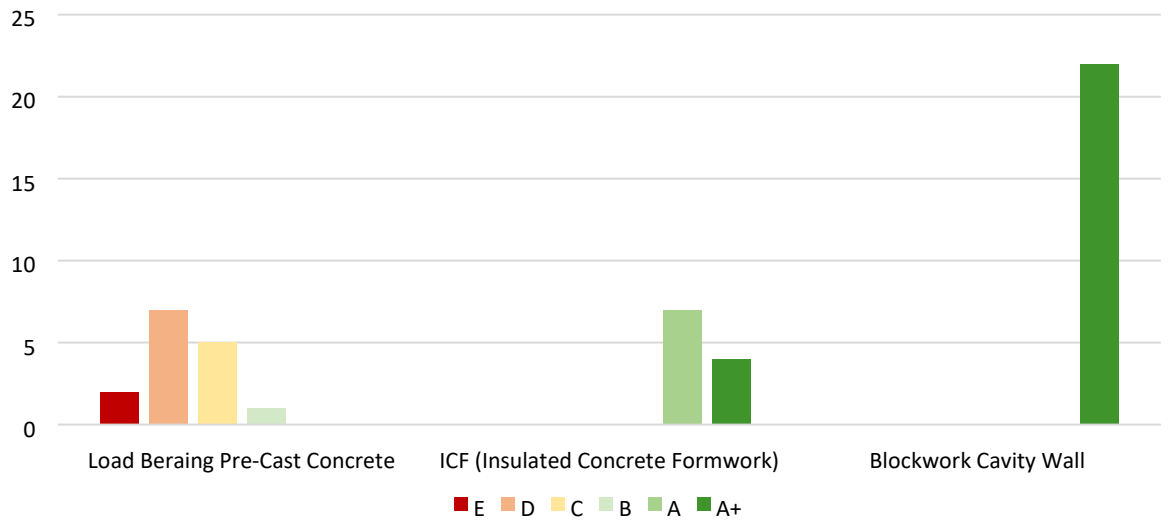


Figure 2: BRE Ratings Quantified (External Wall Systems)

Although the full selection of ICF Systems ranked within the guide achieve a minimum of 'A' rating which could be considered more than adequate, the complete collection of blockwork cavity wall systems achieve an 'A+' rating.

Evaluating this it can be concluded that the BRE Green Guide find minimal difference between an ICF external wall and more traditional block cavity wall in regards to environmental performance and environmental impact when both are erected in good practice.

BecoWallform System

BecoWallform is an ICF system which has been available in the UK for the past 25 years, similar to most of the products currently on the market it is based on large hollow lightweight block components that lock together into which concrete is then poured.

Within their website they provide valuable data on the costs and build rate of the selection of thicknesses of walls that they offer and are shown in the following (Table. 2).

System (Thickness)	Wallform Component	Concrete	Build Rate
Wallform 250mm	£44.00/m² gross wall area	£12.20/m²	4.0m²/Manhour
Wallform 313mm	£48.00/m² gross wall area	£12.20/m²	3.5m²/Manhour
Wallform 375mm	£72.00/m² gross wall area	£12.20/m²	3.0m²/Manhour
Wallform 438mm	£96.00/m² gross wall area	£12.20/m²	3.0m²/Manhour

Table 2: BecoWallform System Specification

As well as offering a build rate at least twice as fast as traditional brick and block masonry the BecoWallform system can be constructed in almost any weather conditions unlike the traditional alternative.

RESEARCH METHODOLOGY

The objectives of this study are based around answering the core question, whether insulated concrete formwork is a viable alternative to established masonry construction methods in mainstream British housing?

The methodology of this research paper was developed on the basis of gaining feedback and experiences of industry professionals during their careers. Individuals will be requested to provide information regarding the residential sector, ICF construction and traditional masonry. The questionnaire survey will establish an idea of what the respondents prioritise within construction and their opinions on various methods. This approach has been selected as it is the most efficient data collection technique.

In addition to this, following the thorough study of the costs presented by BecoWallform a sketch proposal was submitted to the manufacturer with the intentions of producing a price comparison of two identical appearance schemes harnessing two conflicting construction methods (Insulated Concrete Formwork & Traditional Masonry).

Cost Enquiries

The drawings provided to BecoWallform proposed a new single-storey contemporary dwelling with basement car port, refer to attached.

Based on the proposal BecoWallform prepared a schedule of the necessary components along with project costings and estimations for both concrete needed to fill the formwork and manhours required.

Table 3: Material Cost Summary

Ref. Number	Component	Unit Price	Quantity	Total Price
3130	313 Wallblock (Length 1125mm)	£46.00/m²	247.5	£11,385.00
3714	Endset	£1.00/Pair	200	£200.00
3730	Endpiece	£1.00/Unit	400	£400.00
3808	313 Lintel Block	£26.75/m	42.5	£1,136.88
3809	313 Floor Edge Block	£19.75/m	80	£1,580.00
3717	Packing Pieces (Length 750mm)	£1.10/Pair	75	£82.50
3845	313 Firewall Block	£49.95/m²	52.5	£2,622.38
3845CB	313 Corner Block	£34.50/Pair	16	£552.00
3846	200 Core Endpiece	£2.65/Unit	25	£66.25
			TOTAL	£21,630.00

Quantity of concrete: 47.75m³

(Typical concrete specification would be based on a c.25 pump grade mix)

Cost of concrete: £118.10/m³ *

Total Concrete Cost: £5,639.28

Manhours required: 145 hours

Labour Costs (rate to be consistent between systems): £20.17*

Total Labour Charges: £2,924.65

Table 4: Basic Price Comparison

	BecoWallform System	Traditional Masonry	Margin
Wall Components	£21,630.00	£23,336.78*	£1,706.78
Concrete	£5,639.28	N/A	£5,639.28
Labour	£2,924.65	£10,085.00**	£7,160.35
TOTAL	£30,193.93	£33,421.78	£3,227.85

*Prices determined from BCIS Building Maintenance Price Book 2015

**Manhours required estimated at 500 in accordance with BCIS building rates

SURVEY RESULTS

There are multiple occupations within construction, each of which play a pivotal role in the success of the development. From approaching a large variety of professionals it could be discovered whether the general opinion on the subjects is consistent or relative to their occupation.

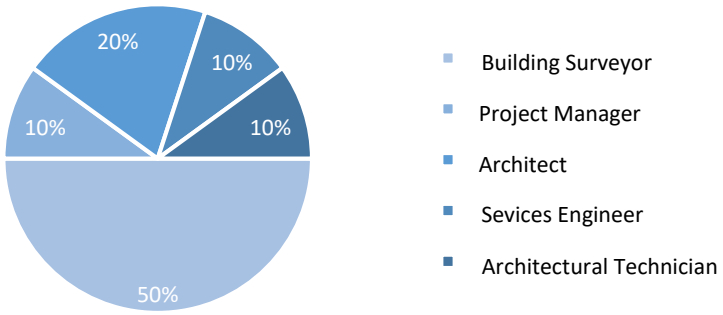


Figure 3: Breakdown of respondents by occupation

Respondents were also asked to identify from a selection of construction techniques which of the following they had encountered during their time in the construction industry.

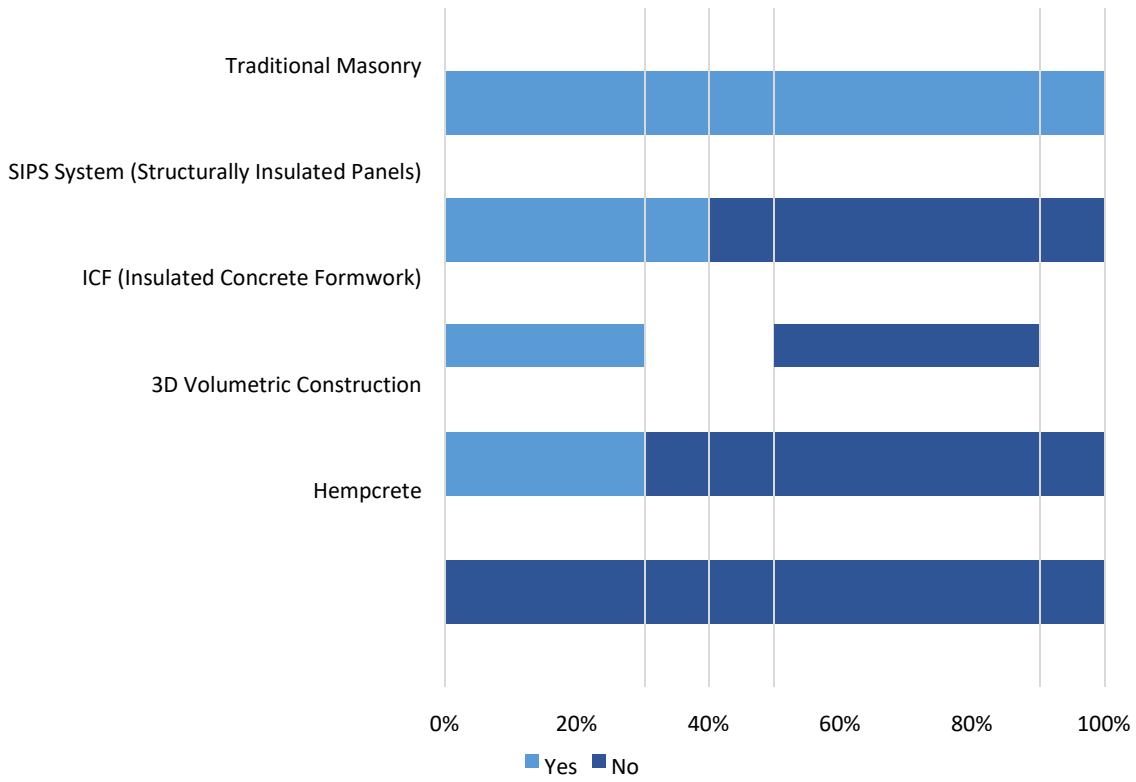


Figure 4: Methods of construction encountered by respondents

The result of this enquiry showed 100% of the respondents had experience with traditional masonry, while only 30% had encountered an ICF system, this could be interpreted as justifying the principle of the paper, that ICF (Insulated Concrete Formwork) is still avoided in construction yet having demonstrated its attributes as a valid substitute to traditional brick and block masonry.

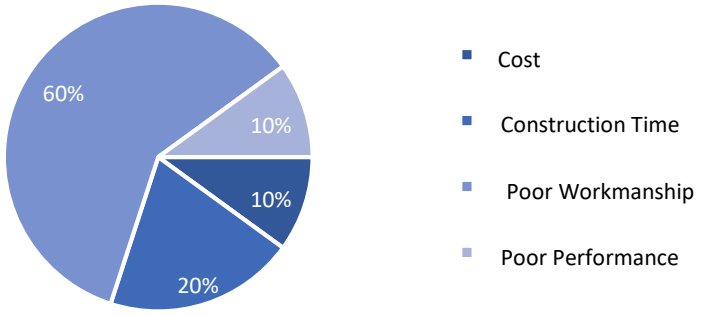
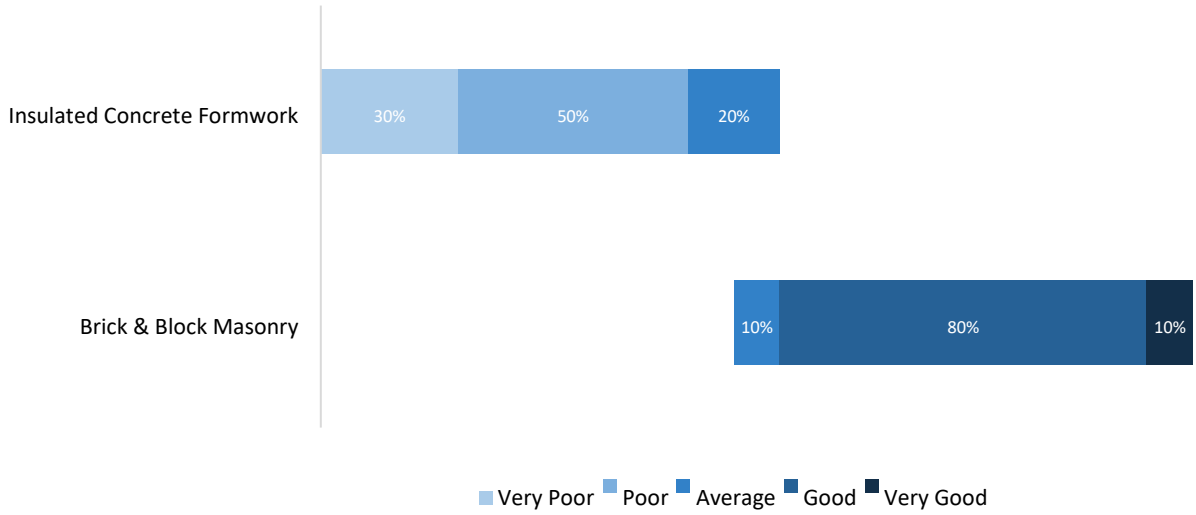


Figure 5: Greatest problem with traditional masonry

Identifying what the respondents recognised as the greatest problem with traditional masonry as presented in (Figure. 5) would then help to define what aspects must be addressed by the alternative methods of construction.

With the majority suggesting poor workmanship is the core problem to the method does this suggest a link with the various reports across the UK highlighting the skills shortage within the construction industry? The most recent research, by Scape Group, indicated that within the Midlands area the shortage has reached 'breaking point' with the results revealing that 85% of public sector contractors across the region said that the shortage of skilled workers has negatively impacted the quality of projects.

Figure 6: Respondents level of knowledge within following fields



From (Figure. 6) it can be seen that over half of the industry professionals who participated rated their knowledge below average; thus showing a positive correlation to (Figure. 4) where the majority of partakers responded that they had no experience with ICF Systems. In addition to this a selection of the respondents requested further information following the questionnaire on ICF systems to broaden their understanding on the matter.

On the subject of heating costs, 75% of participants stated that they *would* consider relocating to another property if it was to offer substantial reductions, while the total reduction was not defined within the question, the response is significant as it displays homeowner's value how well their homes perform. This information could be interpreted as to validating the general appeal of low energy housing of which ICF systems can be employed.

When asked their opinion on why they think Insulating Concrete Formwork is relatively uncommon in the UK, several participants assumed it was due to the inadequate experience of the contractors and a lack of incentive for developers. Other noteworthy responses included reference to it being a non-standard method of construction which may deter building contractors or a system in which planning officers may have reservations on.

Discussion/Analysis

The ICF building method primarily must be accepted as an improvement on traditional brick and block masonry prior to it being adopted more frequently nationwide.

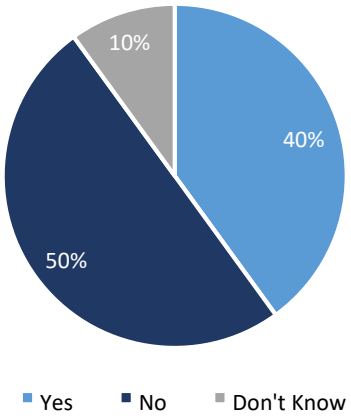


Figure 7: Respondent opinion on whether ICF is an improvement on Traditional Masonry

While there are numerous literature sources endorsing the use of ICF systems, 50% of the responses within the survey disregarded it as an improvement to traditional masonry. This response could be attributed to the partakers lacking knowledge in the system as shown in (Figure. 6) or their preferred familiarity with traditional masonry.

From the conducted survey it was also evident that a substantial amount of respondents blamed the cost of training required for ICF was a deterrent in the selection of construction system. However, an investigation into multiple ICF Manufacturers training charges contradicted the previous belief.

One of the largest reasons of why the approach is yet mainstream is the lack of incentive to housing developers who already have complete designs using the traditional method. The idea that they would spend vast amounts of money on new ICF designs is quashed when they can instead continue to utilise old plans.

Table 5: ICF System Training Costs

ICF System	Training Provision Charges
BecoWallform	Free Onsite Training & Technical Advice
Durisol	Free Training Courses
Nudura	£150.00 Training Programme
Logix	Comprehensive Logix Installer Course

CONCLUSION

Summarising the results acquired within the case study conducted by Daniela Mackova & Marcela Spisakova it is evident that ICF has benefits to offer in regards to performance, and it is currently restricted by its lack of publicity as displayed within the survey.

In theory the system could easily be embraced if there was to be a shortage of bricks within the UK or a sudden lack of skilled workers, but until a crash as such occurs bricks and blocks will remain the firm favourite building system of housing developers. As evidenced within the conducted survey the public like familiarity and with the mass of people with skill to build in brick and block in comparison to ICF, a mass overhaul would be required to reverse this.

The ICF Systems currently available are more appropriate for those intending to self-build who want to pursue the high performance standards Insulated Concrete Formwork is capable of achieving.

For any sort of large scale encouragement of the system, data must be published displaying the long-term performance of various examples across the country to boost the public perception of ICF building systems in conjunction with educating them on how ICF can be successfully implemented.

To conclude Insulating Concrete Formwork has substantial potential to reduce build times but based on the findings of this research is unlikely to overtake brick and block masonry as the default housing construction method in the near future.

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DEVISING AND DELIVERING AN URBAN CITY AT COMMUNITY LEVEL

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Keywords: Masterplan, Regeneration, Urban and Community.

Abstract

Masterplanning has attracted renewed interest in recent years, moving beyond the parameter of a conventional land-use plan to an approach that conveys a vision for the future of an area. (Ardron et al., 2008). The implementation of this approach establishes a guideline for the city in question towards urban regeneration. However, the problem with delivering this 'refined city', is the thorough neglect of the communities that will be affected by the change. This study will explore the effectiveness of local community participation as an integral strategy to masterplanning. Primary data was acquired through the administration of structured questionnaires to local communities, private developers and local council authorities. Furthermore, the associated experiences and feedback were compared against the existing related literature to conclude this study. The response pattern summarises that there is no better way to design for the public than collaborating with the public in the design itself. They are defined as the ultimate users of the buildings and spaces created, therefore; at the centre of any successful masterplan. Two cities within the United Kingdom which are progressively expanding towards urban regeneration were briefly highlighted as a case study. This analysis will be based upon each city's community contributions and collaborations towards its vision for urban rejuvenation through a local development plan. The results conclude that the overall blueprint for the future of any city begins at community level.

INTRODUCTION

Over the last decade, it has become obvious the continual developments and building taking place within the inner areas of many cities and towns. Anyone living or even visiting any city in the United Kingdom will be familiar with construction sites that seem to spring up new buildings overnight. Plus, the sight of numerous cranes towering the skyline, as buildings are constantly being pulled down and built anew. Such is the scale of the regeneration agenda that will help transform towns and cities in the UK; both in terms of the way people will live in them and its overall appearance.

The term regeneration used within this context is defined as the revitalisation of unused and underutilised spaces; thereby transforming them into places people want to live, work and play in. This regeneration process is about the physical development of urban spaces and the understanding of great cities and what makes them truly great. Cities are constantly developing, 'they are never finished objects; Land uses change, plots are redeveloped, the urban area itself

expands and, occasionally shrinks' (Jones and Evans, 2008). So, with growth comes new challenges as its population increases.

Masterplans are structured regeneration plans which elaborates the vision for the significant change of the area over the long run. The intention of this device is to face the rapid urban challenges and changes that comes with the progression, by diminishing anxiety through the creation of a sense of predictability and inclusion (Ganis et al., 2013). However, this device is sometimes fraught with difficult decision making and user dissatisfaction, because of the effect of the urban change on the users of the space; the main stakeholders.

Stakeholders are individuals who commissions the masterplan (the client)- as shown in image below. This is usually the land owner or in most cases the one who will be financing the project. Regardless, the local communities should be given opportunities to get involved or share their views. They are just as important as the landowners and their opinions just as vital. The core function of masterplanning is to merge the needs of stakeholders across public, private and community interest. However, there is still an apparent neglect of the local people's needs towards the urban renewal plans. This paper will highlight the effect of community planning on urban regeneration in the United Kingdom.

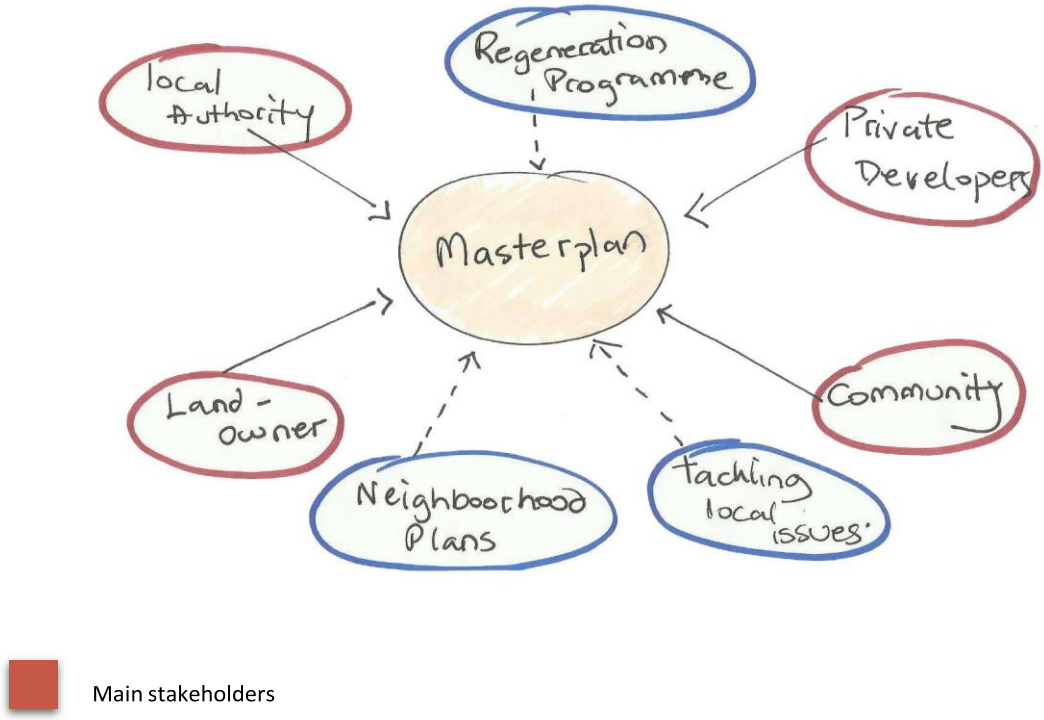


Figure 1-(image reference is BHSF,2014)

LITERATURE REVIEW: Power to the People?

The government has proposed certain policies and guidelines to place the people at the heart of decision making in the planning system. The Code of Practice (2008) is an Act that ensures the duty of the developers to consult. That is, it provides a guidance which public consultations

in England should conform to. It consists of the process of consultation, the related purpose, inclusion, presentation and feedback and requires a practical length of time for discussions. (Whereas a 12week period is suggested).

Another important policy is stated within The Local Planning Act 2008. In section 47 of this Act, the guidance relates to Nationally Significant Infrastructure Projects (NSIPs) whereby promoters must consult with local authorities, local communities and other key individuals and bodies when working on proposals. A Statement of Community Consultation is required and must be published prior to submission. This statement was introduced as part of The Planning and Compulsory Purchase Act (2004), which states how and when the public will be involved in the preparation of development plans.

Leeds is a city in West Yorkshire, England; that is progressively expanding towards urban renewal. Hence, its progression through the aid of community contributions and collaborations is explored as a case study. Leeds City Council's Statement of Community Involvement (SCI) was adopted in February 2007, to set out the measures for community involvement in planning applications. Some of these planned approaches include:

- Involving Ward Members, Town and Parish Council within scheme development.
- Public exhibitions.
- Setting up community/neighbourhood forums.
- Meeting with planning officers at initial design stage.
- Bespoke website providing clear information.
- Getting public attention through information sheets/leaflets.
- Time allowances for decision making.

London is the capital of England; it is regarded as a 21st century city, because it was known as the second most populous urban area in the EU according to Wikipedia. Hence, its progression towards urban renewal via Community Involvement is explored as a case study.

London is divided into boroughs and each region is responsible for its Statement of Community Involvement (SCI). Each SCI states how the communities will be consulted and involved when preparing planning policies and deciding applications in the City.
Some of the standards in consultation on planning policies include;

- Early and continuous engagement.
- Clear communication with public, members and officers.
- Effective planning and timetabling.
- Inclusivity.
- Public view should be respected and considered. Effective feedback/response.

The Localism Act 2011, is an Act of Parliament that aims to facilitate the transfer of decisionmaking powers to councils and neighbourhoods, giving the local communities greater control over local matters. This policy, which received Royal Assent on 15th November 2011, contains a number of measures proposed to involve the community in city planning.

In Section 122, the Act explains the measures one must take when proposing to make a planning application on any land in England. This implies that, consultation of the proposed application

must be carried out prior to submission. Hence, proposed applications must be publicised to attract the attention of many of those who live or occupy the premises.

Another similar policy to The Localism Act (2011) is The National Planning Policy Framework (2012) otherwise known as NPPF. The NPPF was issued by the UK's Department of Communities and Local Government in March 2012. It sets out the new planning policies for England and how they are to be applied. One of which includes the importance of preapplication engagement and front loading. In Paragraph 188, the policy highlights the significance potential early engagement has on improving the efficiency and effectiveness of the planning application system for all parties. Good quality pre-application consultation enables an improved cooperation between public and private resources and better outcomes for the community.

Alongside the Localism Act 2011, The Pre-application Consultation with Communities (2011) is a basic guide published by the Government in February 2011. It sets out information concerning pre-application consultation. Some of this vital information includes:

- The requirement for developers to consult communities, prior to submitting certain planning applications, in accordance with Town and Country Planning Act (1990). For instance, it is compulsory to carry this out with applications involving more than 2 turbines or where the height exceeds 15metres.
- Responses received must be considered and not neglected before finalising the proposals.
- Developers must show that they have accounted for the feedback and responses received during community consultation and how they have been taken to account.
- Public consultation as one of the main types of Local Planning Authority Consultation. The local people are considered one of the parties involved in the pre-application stage, and if the application is amended, the LPA will decide whether further publication or discussion is needed.

Neighbourhood Planning was introduced through the Localism Act 2011, whereby communities get involved in planning processes and vital decisions that will affect their area. It opens opportunities for them to contribute in making planning policies and part of the statutory development plans which has real weight in the planning system. It is not a legal requirement by right but communities in England should exercise these rights. There are three classification categories; Neighbourhood Development Plans, Neighbourhood Development Orders and Community Right to Build Order. Neighbourhood Development Plans become part of the local plans and so the policies within them are used in the progression of planning applications. The Development Orders and Community Rights to Build Orders permit communities to grant planning permission for the types of developments they want to see in their area.

Neighbourhood Plans have an advantage over other kinds of plans; it consists of the needs and aspirations of the community which will in turn contribute towards the vision of the wider city. Hence, when producing a neighbourhood plan it is important to consider the pending masterplan for the city. This implies that, the policies produced cannot contradict or prevent the developments already part of the local plan. Section 38(6) of the Planning and Compulsory Purchase 2004 Act, highlights how development plans are determined by the current local plans and any contrary submission would be void, except if validated reasons arise.

The first stage in producing a Neighbourhood Plan is to allocate the boundary of the area, in which the Authorities will review and confirm. Afterwards the members of the committee prepares a draft plan which will raise their needs and the issues related (this could take up to a year or more). Prior to submission of the plan to the Local Authority for examination, the plans are publicised for pre-submission consultation.

RESEARCH REVIEW AND METHODOLOGY

The policies listed above, are some of the major guidelines proposed by the Government to encourage public consultation and participation in planning decisions. As stated, the intention of the Localism Act 2011 is for decision-making to be passed down to a more local level, from local government to local communities. Residents and businesses are given opportunities to make planning policies that reflect their priorities, deliver tangible local benefits that have real weight in the planning system. However, having all these policies in place why then is the public still unaware of the urban changes in the city? why then do developers still carry on developing without consulting local communities? why are communities' opinions neglected in certain planning decisions? These questions serve as the rationale for adopting the questionnaire research approach to evaluate this study.

RESEARCH METHOD

The research method for this study consists of primary data collected via a quantitative and qualitative questionnaire and secondary data from journals, articles, online related reports, and publications documented within local government websites. The research was limited to two cities in the UK; Leeds and London, which are clearly expanding towards a regenerated setting.

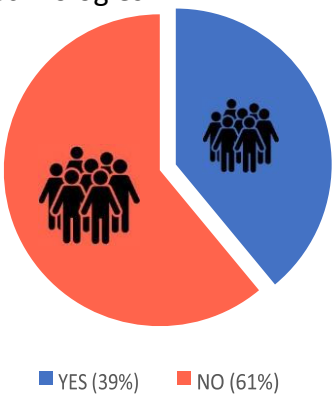
The primary data was obtained via an online questionnaire consisting of 10 questions emailed and (hardcopy) handed out to a total of 102 participants comprising of members of the public, Individuals in architectural and construction sector, building regulations team, Local Authorities, private developers and local communities. 2 recipients could not complete the survey due to certain issues, but the remaining 100 responded and returned the completed survey.

RESEARCH RESULTS

The survey was aimed at individuals and professionals working in architectural/construction related sector, local communities, private developers and local council authorities. Of the 100 respondents, 67% were within the architecture and construction sector, 7% were local authorities, whilst the remaining 26% were members of the public.

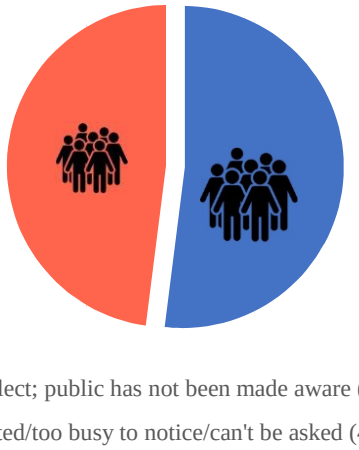
The chart below summarises the percentage of people that are aware of their city's progression towards sustainability, urban design and innovation. With only about 39% of positive responses, it is obvious that not a lot of people are aware of this progression. Majority claim to be unaware, scoring about 61% negative responses.

Chart 1, Are you aware of your chosen city's' progression towards sustainability/urban design/innovative technologies.



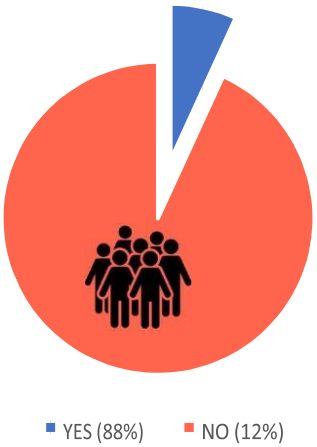
When reviewing why the people claim to be unaware of their city's progression towards sustainability/urban design/innovation, the main reason identified was public neglect. With a little over 50% responding that the public has not been made aware of its regeneration plans. However, almost half of the total respondents claimed to be ignorant and less interested in the urban happenings of the city.

Chart 2, are you unaware of the regeneration of your chosen city because of?



Moreover, those surveyed overwhelmingly believed that projects or designs require the input of the community/public, whether it be their opinions, contributions or engagement. With over 80% of positive responses regarding public participation in local planning decisions.

Chart 3, Do you feel projects or designs require the input of the community/public? Whether it be their opinions, contributions or engagement?



When asked their opinion on the most important factor in any development project whether it be creating buildings, spaces, and bridges or landscaping; about 50% concluded that the effect of the end users is the most important factor. The satisfaction of the client and the transformation of the area was ranked as the second most important factor, indicating that this is not the most important factor in development projects. However, it does highlight a secondary determinant in the development of various projects.
In addition, 90% of the respondents felt these factors they have chosen has an integral role to play in their city's future development plan. Implying that they consider the factors chosen to be vital in city planning.

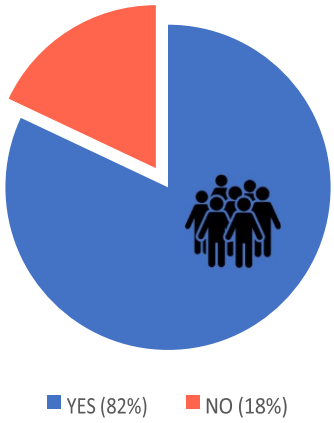
Table 4, Which 3 factors do you consider most important in any development project? -whether it be creating buildings, spaces, bridges or landscaping. (in its order of importance; 1-3)

Factors	%	Ranking; in its order of importance
The effect of the end users	50	1
The satisfaction of the client	17.9	2
The initial design	-	-

The standards of the local council	-	-
The transformation of the area	17.9	2
The historic character of the area	-	-
The price/budget	-	-
The effect on the environment	37.5	3

Finally, respondents were asked if they would like to have a say in their city's design and development plans. It is evident in chart 5 that majority answered 'yes' to providing their input in planning. Also, it is notable that this response pattern attained a similar percentage as that of the question regarding public participation in local decision making. (Reference to chart 3). Hence, this means that the public are aware their inputs matter, so they want to participate.

Chart 5, would you like to have a say in your city's design and development plans?



DISCUSSION AND CRITICAL ANALYSIS

In this section, the associated experiences and feedback will be compared against the existing related literature to conclude this study. Over the last decade, the significance of community involvement in neighbourhood regeneration plans -creating sustainable places where people want to live in- has been at the heart of policy. The legal requirement for consultation encourages consultants to let people know what they are proposing and why, giving them the chance to respond. The responses will be considered with an open mind before continuing with proposals.

From the survey, it was established that;

- The public claim to be unaware of the regeneration plans of the city, which contradicts the guidance highlighted in the Town and Country Planning Order (2015) Article 15 (1), which requires applications for planning permission to be publicised by the local planning authority. In addition, The Code of Practice (2008), The Nationally Significant Infrastructure Projects (NSIPs) policy within The Local Planning Act 2008 and The Statement of Community Consultation policy under The Planning and Compulsory Purchase Act (2004) all enforce the need for public consultation. This implies that, all development plans are published prior to submission as a requirement by Law. So then, if these policies claim that the people are aware or should be aware and the public claim to be unaware, herein lies the problem. This is because the findings show that there are policies proposed for community involvement in planning, but the public is unaware of these rights. According to the June 2015 CIHT report, one reason could be that 'the majority of those who engage in planning are over 55 years. Response rates to a typical pre-planning consultation are around 3% of those directly made aware of it. In Local Plan consultations, this figure can fall to less than 1% of the population of a district'. Hence, the statistics concludes that less and less people are made aware not to talk of engaged in planning because they fail to engage the younger age group.
  Further investigation involving an increased number of participants; taking to account age group is recommended to deliberate this issue further.

- The public blames their obliviousness for public neglect, as they feel that they are not being involved or relayed matters regarding local planning. According to the findings a little over 50% of the participants stated that they are neglected in their city's progression towards sustainability/urban design/innovation, hence the reason why they claim to be unaware of the regeneration plans of the city. Although, the NPPF (The National Planning Policy Framework) encourages participation with the local community prior to submission, but this is not always the case as some developers still go ahead because some policies are not compulsory.
  The Neighbourhood Planning was set up to provide opportunities for the public to contribute in making planning policies and take part in the statutory development plans because their say has real weight in the planning system. But the issue is that it is not a legal requirement but a right for communities in England to exercise. The Development Orders and Community Rights to Build Orders permit communities to grant planning permission for the types of developments they want to see in their area. That is to say, The Neighbourhood Planning Act has been provided for each region so that the people within their communities are not neglected but rather made aware of their city's urban progression and allows them contribute towards it. This finding will need further investigation involving the wider city to conclude whether the public is actually being neglected regardless of the policies inplace or because some policies regarding consultation are not legally required or mandatory, so the public claim to be ignorant of their rights.

- They feel their inputs, contributions and engagement matter, whether it be designs or projects. Hence, they should be considered in planning decisions in accordance with the Localism Act 2011. In Section 122, the Act explains that public consultation of the

proposed application must be carried out prior to submission. Hence, proposed applications must be publicised to attract the attention of many of those who live or occupy the premises. This finding agrees in full, with the related literature.

- They consider themselves to be the primary factor in any development plan. The respondents concluded that the effect of the end users is the most important factor in the development of various projects, which can also be referenced within the Neighbourhood planning guidance. This guidance identifies the needs and aspirations of the community which will in turn contribute towards the vision of the wider city. This agrees that the end users are at the heart of masterplanning, as they play an integral role in their city's future development plan. Implying that they consider themselves as a factor which influences regeneration.
  This finding agrees in in full, with the existing literature, as Victor Papanek once said, 'the only important thing about design is how it relates to people'. That is putting the people at the heart of the design.

- Finally, they want to participate. The SCI (Statement of Community Involvement) highlights participation as key because it shows that one is interested in the people's opinions and want to consider their views towards the proposals. This can be in various forms such as through focus groups, forums, surveys, regular meetings with public representatives and even hands-on engagement.
  There is an ancient proverb that says, 'tell me something and I will forget it, show me something and I will remember it, involve me and I will understand it'. Hence, this finding agrees in full, with the provided literature.

CONCLUSION: 'The Effect of Community Participation on Urban Regeneration in the UK'

The intention of the regeneration plans is to encourage and enable the developers to engage more effectively with those who will be directly affected by the work they undertake. Local users are bundles of information which cannot be obtained elsewhere. They hold descriptive insights as to livelihood and what will or what might not work in an area. Furthermore, engaging the public can construct the awareness of matters that are not expressed by traditional 'data-gathering exercises'. For instance, in transportation projects, STATS19 data may show collision clusters, but the perceptions of the local users can provide valuable data on impacts as well as safety issues. Additionally, successful masterplans are flexible and must have involved the community and other stakeholders from the start, giving the plan an appropriate base and better chance to come to realization.

The secondary data highlighted that public consultation is a determinant factor in urban planning processes. Hence, it improves the outcomes of projects and the likelihood of its success. 'If you create somewhere people want to live and work, then that will attract and sustain prosperity in the area'- (Coleman, 2016). Examples of community-involved projects that have been successful in the UK include;

Case study 1, Kirkstall Forge, Leeds

The city of Leeds, has the largest community engagement in planning, with 35 pending Neighbourhood Plans than any city other than London. This case study highlights the effect of key community participation which enabled the success of the project. The local community and ward members awarded its scheme as the best practice example of community involvement in planning procedures.

The creation of a community forum for the Kirkstall Forge site provided regular updates all through the life of the project. The progress was further supported through exhibitions at local events, on the local media and the projects webpage. Other commendable strategies applied include regular meetings and presentations, issuing brochures about the development, providing a website dedicated only to information regarding the project, using social media to publicise information about the development, displaying a public notice board/posters/leaflets in front of the site/at local shops/community buildings, hosting public consultation events.

So far, this development has created 45 new local jobs, 45 completed training opportunities, 6 jobs for the long-term unemployed, 10 apprenticeships and 250hours of industry support and volunteering time.

Case study 2, Green Man Lane Estate, Ealing, London

This case study emphasises on how a clear, concise resident engagement plan initiated the success of a high-level scheme for the people involved. The Ealing Council resulted to engaging the public at the early stages of design by setting up public meetings, series of workshops and visits to other regeneration schemes to review and present suitable proposals for the site. The Council only resulted in proceeding with the development on the basis of the positive support and feedback from the public exhibition. This new project in the run-down 1970s estate in Ealing, West London, will provide 764 new homes which will contribute to the wider scheme of the regeneration of London.

The phase of this community-led development will not only provide a neighbourhood for people to live, work and generally feel safe in, but also will involve the development of new community buildings and facilities.

The findings from the primary data concluded that there are several policies imposed to engage the public in regeneration plans but the public claim to be unaware of them. That is to say, clearly the government has provided these rights and mediums of which the public should be involved in planning, but the data shows that the people have responded negatively and do not feel part of the equation. For now, effective strategic public awareness of their rights and the importance of their contribution in the planning system is recommended to help establish better communication. One effective principle of good engagement highlighted by The Leeds City Council, is 'Timeliness'. This means that consultations and involvements should begin right from the onset before the final scheme is prepared. This key principle which can be referenced in both case studies resulted in the success of those projects. Other engagement strategies implemented which guaranteed their success and which stakeholders should apply is public exhibitions, establishing community forums, hosting consultation events, providing a website dedicated only to information regarding the project, consultation meetings and local

advertisements of the project through local media, social media like Twitter, websites, brochures, public notice boards and posters.

The question of public awarenes policies are communicated to the people and the effectiveness is questionable and requires further study to establish what methods are used and improvements that can be made to make the public feel included.

In summary, the primary research establish the initial aim of this paper, which has been answered, identifying that the public are indeed neglected in the planning system. Although, further investigation involving an increased number of participants; taking to account age group is recommended to improve this research. Nonetheless, there are many benefits of public participation in the UK, but its effectiveness as an integral scheme to masterplanning is most essential. Developments do not necessarily have to be community-led or communitydriven to be successful, it is the participation and consultation that counts. Devising this strategy of involving the community in city matters, will in turn stir its plans towards the delivery of a renewed setting.

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THE IMPORTANCE OF COMMUNITY INVOLVEMENT IN HOUSING DELIVERY IN WESTERN CAPE, A CASE STUDY IN DELFT

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Keywords: Community involvement, Housing delivery, South Africa, Quality

Abstract

In Western Cape there is a huge demand for housing in the post-apartheid era. Government funded housing developments are there to meet these needs and keep up with promises made by the state. Whilst the government has attempted to meet the increasing demands for low-cost housing, research reveals that the focus is on quantity of the houses not quality. There is a sheer number of low-cost houses that has failed to conform to quality expectations, and one of the major factors amongst others have been attributed to the lack of community participation in housing delivery in the Western Cape. Therefore, the study is aimed at evaluating the importance of community involvement in housing delivery in the Western Cape. A quantitative approach was adopted, and a random sampling technique was employed to select the survey participants. Response data was subjected to descriptive analysis. The salient findings include the involvement of community in housing delivery contributes to: creation of employment within the community; developing skills in the community, and assisting the community to take ownership of their houses. Based upon the findings it can be concluded that community participation fosters effective project implementation and sustainable development, empowers communities and builds their capacity to be self-reliant and take charge of their own development.

INTRODUCTION

The right to adequate housing is one of the most essential basic human rights entrenched in the constitution of the Republic of South Africa and it speaks to the restoration of dignity to the millions of South Africans (SAHRC, 2015). Although the new democratic Government in all under- serviced areas has made tremendous contribution since it came into power in 1994; the housing issue is still hotly contested socially and politically, which will take some time to resolve (SAHRC, 2015). The poor implementation of housing policy is denying the beneficiaries to some extent their expectations and basic needs they wished for, because of the poor quality of the houses (Ngwenya, 2016; AGSA, 2008) and the size of the houses do not cater for big families. The poor beneficiaries desire to live in a conducive housing environment, a place they can call a home, which is close to amenities such as hospitals, schools, shops and all basic needs (Aigbavboa & Thwala**,** 2011).

In spite of the numerous measures to improve housing backlog focussing on the number of houses that has been delivered; research shows that beneficiaries of low cost houses desire to

leave in a conducive environment, but the housing condition has been gradually deteriorating without due consideration to the needs and expectations of the beneficiaries by the housing providers *(*Aigbavboa & Thwala, 2011). This is further exacerbated by the fact that housing delivered were incomplete, shoddy with poor workmanship which leaves people dissatisfied (Mnisi-Mudunungu, 2011). This is corroborated by Ha (2008) who opines that failure of many housing projects may be traceable to the lack of knowledge with regard to the determinants of housing satisfaction from the occupants of the houses. Fatoye (2009) and lahndepera and Tiuri (1999) note that community satisfaction is not only a matter of handing out a new house to beneficiaries, but a life cycle issue which has to be taken into account right from the policy initiation phase. The importance is based on the fact that most problems in the existing low-income housing delivery environment are the result of neglecting the beneficiaries. For that reason, Ha (2008) and Zonke (2015) opine that the success of housing programmes does not only depend on merely provision of housing units, but also on other factors that affect the needs and expectations of the residents. Hence, the South African National Department of Human Settlement must take a proactive step with regard to understanding the needs of the beneficiaries or community (Burgoyne, 2008).

There are sheer number of factors affecting housing delivery, some of the major factors amongst others include lack of participation of beneficiaries into housing delivery process, lack of funds, lack of transparency in housing delivery, lack of proper planning, lack of proper monitoring and evaluation (Burgoyne, 2008; COHRE, 2009; Department of Local Government and Housing, 2005). However, in the case of the N2 Gateway project in Joe Slovo and Delft informal settlement in Cape Town, the lack of participation seems to be a constant source of frustration throughout the planning to the implementation phase. Likewise, the low level of communication and information-sharing with communities has been criticised as well (COHRE, 2009:34). To provide an overview of these perspectives, this paper would attempt to examine community involvement in housing delivery on the N2 gateway project with the aim of determining the importance of community involvement in housing delivery in Delft informal settlement in the Western Cape Province. The importance of this paper is underpinned by the need to examine the lack of communication and noninvolvement of all stakeholders in housing delivery process which often results into conflicts and extreme delays in delivery of houses.

CUMMUNITY INVOLVEMENT IN HOUSING DELIVERY

Importance of Community involvement in housing delivery

According to Sikota (2015), community involvement in housing delivery is very important as it transforms development practice by involving people in projects intended to benefit them. This demonstrates the emphasis put on the need to include people in development projects, especially those that have an impact on their lives. Community participation is an active process by which beneficiaries or groups influence the direction and execution of a development project with a view to enhancing their well-being in terms of income, personal growth and self-reliance (Chirenje *et al.,* 2013). According to Havugimana (2013), community involvement is a social process whereby specific groups with shared needs, often but not always living in a defined geographical area, actively pursue identification of their needs, make decision and

establish mechanism to meet these needs. According to the ICMA, (2003) community involvement provides a forum for residents to become informed about communal affairs and actively involved in making decisions that ultimately impact their community. Meaningful community involvement is beneficial in several ways which: improves information flow, improves community understanding of local government; allows for community advocacy, fosters collaboration, minimizes conflicts, and may promote environmental justice. Failure to adequately inform and involve the community can cause significant delays as a result of public reluctance or outright opposition to the project (Chirenje, Giliba & Musamba, 2013: Khan, 2005). According to Lizarralde and Massyn (2008), the adapted ladder proposed by Arnstein proposes eight levels of community involvement including empowerment, partnership, conciliation, dissimulation, diplomacy, informing, conspiracy and self-management. Empowerment represents the highest level of participation in which community members demonstrate actual control of the project and influence the process and outcomes of development. Conspiracy being the seventh level at the bottom of the ladder represents the cases in which no participation in the formal decisionmaking process is allowed or even considered. The ladder displayed in Figure 1 shows the levels of community involvement and empowerment (Lizarralde & Massyn, 2008).

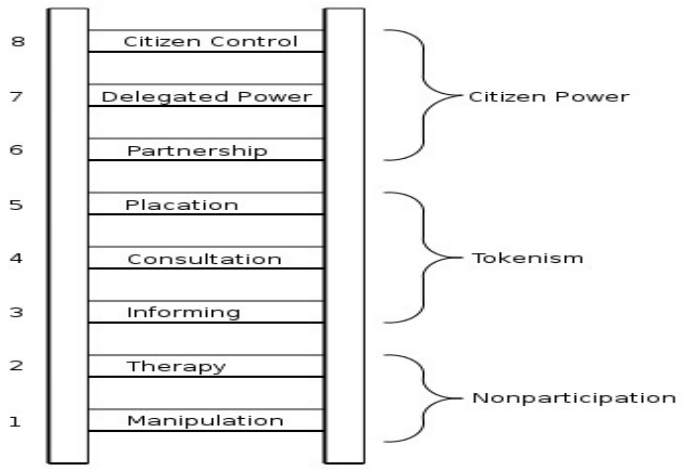

Figure 1: Ladder of citizen participation, Source: Arnstein (1969)

Stages of Community Participation

According to Mthabela (1999), participation goes through a series of stages including involving beneficiaries on housing programmes in the planning and management; and their settlement has been recognised as a desirable guiding principle for housing projects. Havugimana (2013) defines participation or involvement as collaboration, in which people voluntarily or because of some influence or incentives, agree to collaborate with an externally determined development project often by contributing their labour and resources in return for some expected benefits. Community participation in project planning and management is essential in enhancing development at the basic community level. It also promotes equity, legitimises decision-making processes, builds and strengthens self-determination and influences people towards a more democratic behaviour and development (Mathabela, 1999). A study conducted by Ofori (2008) reveals five stages of community participation in project implementation which

includes initiation, planning, design, implementation, and maintenance. Ofori (2008) states that all parties are expected to contribute to the decisionmaking process and collaborate to ensure that the project is successfully carried out or executed and effectively maintained. Project development begins with initiation which is represented at the base of the triangle; it goes through the planning, design and implementation stages before completion. Once this is achieved, the project has to be maintained in order to achieve the desired benefits (Havugimana, 2013). Project implementation involves various tasks and experience shows that, at least, local populations are recruited to work as labourers on projects that affect them. But they need to be empowered, trained and provided with incentives to help manage projects (Ofori, 2008). The actors of decision making process are the project implementing agency which are made up of technical experts, the government which is represented by its agencies and other recognized organizations, and the local communities (Havugimana, 2013).

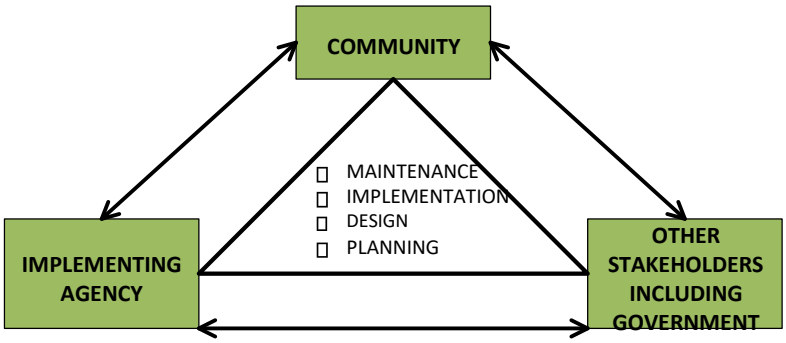

Figure 2: Model of interactive of participation in project development, Source: Ofori, (2008).

Obstacles in involving community in housing delivery

It is often argued that participation is crucial for the performance of low-cost housing projects. It is also believed that users make the most appropriate decisions about their own housing solutions and that they know what is best for them (Lizarralde & Massyn, 2008). Nonetheless, Lizarralde and Massyn (2008) contend that community participation may be problematic in the sense that it may be time consuming. It is evident that conceptualising the issue, decision making, implementation and evaluation requires people participation all the way. Once people have articulated their aspirations and become conscious of their right, they will not be likely to settle for less without argument (Mathabela, 1999). Some of the common constraints to the community-based approach include:

(i) Difficulties to integrate the community in the design and management of the project (Lizarralde & Massyn, 2008).
(ii) Difficulties in building up mutual trust between agencies and communities (Lizarralde & Massyn, 2008).
(iii) Reluctance on the part of the governments to give substantial power to lowincome groups ((Lizarralde & Massyn, 2008).
(iv) The reduction of participation to sweat equity instead of active participation in decision making (Lizarralde & Massyn, 2008).

(v) Empowering people to take control at local level inevitably leads to conflict (Khan, 2005).

Benefits on involving Community in Housing Delivery

Lategan (2012) states that involving community should not only impart physical benefits in the form of delivering homes of a better quality, but should also provide for longer term benefits such as economic growth and development and provide the opportunity for skill transfer to take place. The involvement of people and the utilization of local resources generate a sense of ownership over the development interventions by the local people (Letagan, 2012). The Housing Code (SA, 2000:7) states that housing should be developed in a manner which empowers communities and individual beneficiaries, through skills transfer and economic development. Low-cost housing projects should as far as possible provides the community with employment opportunities and the opportunity to practice skills learnt as a trade. Transferring these skills can be accommodated and facilitated with the use of effective participation and communication between stakeholders (Lategan, 2012; Zonke, 2015). Kumar (2002) identifies a number of factors considered as benefits of participation of people in a programme. Firstly, Kumar (2002) states that participation ensures efficient utilization of resources. Secondly people's participation increases effectiveness; thus projects can be finalised within the time schedule; they can also carry out monitoring and evaluation and draw a progress report (Kumar, 2002). Thirdly, community participation reduces dependency and increases self-reliance.

METHODOLOGY

Research Design

This study adopted a quantitative research. The primary data was gathered via a questionnaire survey from the beneficiaries of houses on the N2 gateway project, community of Delft, contractors, consultants, and Government officials involved in the N2 gateway project. Both open-ended and closed-ended forms of questions were adopted for this study. The questionnaire was sub-divided into five sections, Section A covered general questions designed to obtain background information of the respondents. Section B was designed to solicit for information regarding the factors influencing the involvement of community in housing delivery. Section C was designed to evaluate the importance of involving beneficiaries in housing delivery, while section D was designed to examine the extent of community involvement in the decision making processes in housing delivery. Lastly, section E was designed to explore various interventions that can be adopted in order to improve participation of the community in housing delivery. Responses were evaluated on a perceived level of agreement with statements based on a 5-point Likert scale.

Sampling Method and Survey Administration

In order to obtain a fair representation for this study, a simple random sampling technique was adopted to select the respondents. Kirk (2008) describes random sampling as a method of drawing samples from a population so that every possible sample of a particular size has the same probability of being selected. Therefore, simple random sampling was applied in each of the chosen 10th streets in the area to select the survey participants. A total of 60 questionnaires was administered to the respondents, 30 questionnaires were hand delivered to the beneficiaries of the houses who have already occupied their houses, backyarders from Delft and beneficiaries from Joe Slovo informal settlement, while the remaining 30 were administered to the members of NGOs, Government officials and construction professionals. Although the questionnaire was compiled in English in order to facilitate communication, it is important that to note that some of the questions were interpreted in other local languages to accommodate those who did not understand English. Out of the 60 delivered questionnaires, 34 were duly completed and returned, and 30 out of the 34 responses received were found suitable for analysis.

Data Analysis

The quantitative data was encoded using the Statistical Package for the Social Sciences (SPSS), and results were analysed statistically using the descriptive statistics. The Likertscale type questions are discussed based on mean score comparisons.

DATA PRESENTATION AND ANALYSIS

Factors militating community involvement in housing delivery

Table 1 indicates the extent to which the following factors negatively influence the involvement of community in housing delivery. The respondents were required to rate these factors on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). A review of the MSs provides a more comprehensive perspective. It is evident from the ranking of the means of responses that difficulties in building mutual trust between agencies and communities dominates with a mean score of 4.70, given that the MS >4.20 ≤ 5.00, the degree of agreement is between agree to strongly agree / strongly agree relative to difficulties in building mutual trust between agencies and communities.

Table 1: Extent to which the following factors negatively impact the involvement of community in housing delivery

Factor	No	Response (%)					MS	Rank
		SD……SA						
		1	2	3	4	5		
Difficulties in building mutual trust between agencies that are employed by government to facilitate and assist on housing delivery and communities.	30	0.0	0.0	0.0	34.4	65.6	4.7	1
Time consuming for communities and stakeholders.	30	2.3	5.1	0,0	17.0	75.6	3.2	2

Difficulties to integrate the community and design process.	30	0.0	33.3	33.3	33,5	0.0	3.0	3
The reduction of participation to sweat equity instead of active participation in decision making.	30	0.0	0.0	40.2	33.3	26.5	2.7	4
Reluctance on the part of the governments to give substantial power to low-income groups.	30	31.7	9.7	14,7	17.8	26.1	2.5	5
Difficulties to integrate the community phase of the project.	30	0.00	0.00	33.3	66.7	0.00	2.0	6
Reluctance of government officials and stakeholders because of cost involve.	30	16.7	0.0	66.7	33.3	0.0	1.9	7

The hierarchical ranking of the means further indicates that time consuming for communities and stakeholders, difficulties to integrate the community and design process, and reduction of participation to sweat equity instead of active participation in decision making are ranked 2nd, 3rd and 4th respectively. The MSs for these factors are >2.60 ≤ 3.40, indicating that respondents degree of concurrence is between disagree to neutral / neutral. Reluctance on the part of the governments to give substantial power to low-income groups (2.5) and difficulties to integrate the community phase of the project (2.0) are ranked 5th and 6th respectively. The least ranked factor was reluctance of government officials and stakeholders because of the cost involve with a MS of 1.9. Since the MSs are > 1.80 ≤ 2.60, the degree of concurrence is deemed to be between strongly disagree to disagree /disagree / neutral.

Importance of community involvement in housing delivery

Table 2 indicates the extent to which community involvement is important in housing delivery in terms of percentage responses on a 5-point scale ranging from 1 (Strongly disagree) to 5 (strongly agree). Is worthy to note that the first factor obtained a MS >4.20 ≤ 5.00, which indicates respondents concurrence that "community involvement in housing delivery creates employment for the community" can be deemed to be between agree to strongly agree / strongly agree. Community involvement helps in developing skills in the community is ranked 2nd with a MS of 3.8, community involvement helps the community to take ownership of their houses is ranked 3rd with a MS of 3.0, community involvement helps because the community is given a chance to have a say in the project in ranked 4th, and the community can feel a sense of belonging is ranked 5th. However, the degree of concurrence for the second ranked factor may be deemed to be between neutral to agree / agree since the
MS > 3.40 ≤ 4.20, whereas the extent of agreement is between disagree to neutral / neutral for the 3rd, 4th, and 5th ranked factors given that the MSs > 2.60 ≤ 3.40. It is notable that community involvement helps because the community is given a chance to be involved in all the stages of the project and community involvement prevents conflicts between the community and stakeholders are ranked 6th and 7th respectively. Since the MSs are > 1.80 ≤ 2.60 the degree of concurrence are considered to be between strongly disagree to disagree / disagree / neutral.

Table 2: The importance of community involvement in housing delivery

Situation	**No**	**Response (%)**					**MS**	**Rank**
		SD……SA						
		1	**2**	**3**	**4**	**5**		
Community involvement in housing delivery creates employment for the community.	30	0.0	3.1	8.7	26.2	63.0	4.4	1

Community involvement helps in developing skills in the community.	30	0.0	7.3	14.4	27.1	51.2	3.8	2
Community involvement helps the community to take ownership of their houses	30	14.3	0.0	2.3	66.7	16.7	3.0	3
Community involvement helps because the community is given a chance to have a say in the project.	30	20.8	62.5	8.3	8.3	0.0	2.9	4
The Community can feel a sense of belonging.	30	23.0	33.3	29.2	14.5	0.0	2.67	5
Community involvement helps because the community is given a chance to be involved in all the stages of the project.	30	40.7	45.8	21.8	25.0	4.2	2.1	6
Community involvement prevents conflicts between the community and stakeholders.	30	4.5	29.2	8.3	8.0	0.0	2.0	7

Extent of community in decision making process

Table 3 depicts the results obtained from the respondents concerning their opinions with regard to the extent of community involvement in decision making in housing delivery. The ranking of the means indicates that the planning stage had the highest mean score and ranked first, construction stage is ranked 2nd with a MS of 4.00, delivery stage is ranked 3rd with a MS of 3.0, followed by project briefing with a MS of 2.8. The least ranked phase is the initiation stage with a MS of 2.0. The extent of community involvement in decision making during the planning and construction phase in housing delivery can be deemed to be between Maybe to a large extent / large extent since the MSs are > 3.40 ≤ 4.20. In effect, the results indicate that the communities were involved mostly during the planning and construction stage. MSs > 2.60 ≤ 3.40 indicates that the extent of community involvement during the delivery and project briefing phase can be deemed to be between Never to maybe / maybe. The extent of involvement with regard to the initiation / conception stage can be considered to be between not at all to never / never as the MS is > 1.80 ≤ 2.60.

Table 3: Extent of community involvement in decision making processes in housing delivery

Stage / Phase	**No**	**Response (%)**					**MS**	**Rank**
		Not at all……Very large extent						
		1	**2**	**3**	**4**	**5**		
Planning stage	30	0.0	0.0	0.0	30.0	70.0	4.2	1
Construction stage	30	0.0	0.0	0.0	75.0	25	4.0	2
Delivery stage	30	0.0	0.0	15.6	42.2	42.2	3.0	3
Project briefing	30	1.6	42.2	42.2	14.0	0.0	2.8	4
Initiation / conception	30	66.7	33.3	0.0	0.0	0.0	2.0	5

Interventions that can improve housing delivery

Table 4 shows the results obtained from the respondents with regard to various interventions that will improve housing delivery on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree) with a mid-point score of 3.00. More transparency in housing delivery and proper planning are perceived to be the most suitable interventions which may assist in improving housing delivery. Given that their MSs are > 3.40 ≤ 4.20, respondents' degree of concurrence can be deemed to be between neutral to agree / agree. The least ranked intervention is proper monitoring and evaluation with a MS > 1.00 ≤ 1.80, which indicates that

the contribution of this intervention towards improving housing delivery can be deemed to be between strongly disagree to disagree.

Table 4: Extent to which the following interventions contributed to improving participation of the community in housing delivery

Intervention	No	Response (%) SD……SA					MS	Rank
		1	2	3	4	5		
More transparency in housing delivery	30	0.0	0.0	0.0	56.6	43.4	4.0	1
Proper Planning	30	0.0	0.0	17.6	31.4	51.0	3.6	2
Full participation of local people	30	41.7	38.2	0.0	0.0	20.1	2.9	3
More Funding	30	39.7	39.7	0.0	14.8	5.8	1.9	4
Proper Monitoring and Evaluation	30	0.0	0.0	10.5	40.5	40.0	1.0	5

DISCUSSION OF FINDINGS

The findings indicate that factors that have an effect on community involvement in housing delivery include difficulties in building mutual trust between agencies and communities, time consuming for communities and stakeholders, and difficulties to integrate the community and design process. It is notable that the degree of agreement is between agree to strongly agree / strongly agree.

In terms of the extent to which community involvement is important in housing delivery, it is worthy to note that three factors obtained a MS above the mid- point of 3. These factors include; community involvement in housing delivery creates employment for the community, community involvement helps in developing skills in the community, and community involvement helps the community to take ownership of their houses. This is in alignment with the findings in literature, especially that of Lategan (2012), who opines that involving community in housing delivery projects provide longer term benefits such as economic growth and development, provide the opportunity for skill transfer to take place, and generate a sense of ownership over the development interventions by the local people.

With regard to the extent of community involvement in decision making processes in housing delivery, the results indicate that the communities were involved mostly at planning and construction stage. This is corroborated by Lizarralde & Massyn (2008) and Ofori (2008). In particular, Lizarralde & Massyn, (2008) stress that involving community at an early stage (e.g. planning stage) is likely to improve design by ensuring that full advantage is taken of local technology and knowledge of climatological and topographical conditions, and ensuring that the project is fully adapted to the social organization of production. While Ofori (2008) maintains that involving community during the project implementation involves various tasks, and experience shows that, at least, local populations are recruited to work as labourers on projects that affect them.

Regarding various interventions that will improve housing delivery, the findings reveal that more transparency in housing delivery and proper planning are perceived to be the most suitable interventions which may assist in improving housing delivery. It is notable that respondents' degree of concurrence can be deemed to be between neutral to agree / agree.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the findings it can be concluded that community participation fosters effective project implementation and sustainable development, empowers communities and builds their capacity to be self-reliant and take charge of their own development.
From the data presentation it is also recommended that:

- Involving the community in all stages during the delivery of housing projects is imperative.
- Improving participation of community in housing delivery would ensure transparency amongst all stakeholders and subsequently minimise conflicts and delays in delivery of houses.
- The empirical research is limited to data gathered within Cape Town, besides, only data gathered from Delft informal settlement were examined, therefore, the result cannot be generalised. Further research on other informal settlements and in other provinces is recommended to establish if similar findings would emerge.

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BUILDING A CAUSAL MODEL OF VARIABLES INFLUENCING CARBON EMISSIONS IN SOUTH AFRICAN DWELLINGS – AN EXPERTS' KNOWLEDGE ELICITATION APPROACH

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Keywords: Carbon Emissions, Causal Models, Dwellings, Mental Models, South Africa, System Dynamics.

Abstract

There are many variables influencing energy consumption and carbon emissions in dwellings. These variables interact and interrelate in a complex way as a sociotechnical problem. The lack of empirical data to support the relationships among some of the variables has been reported to pose problems to studies within this research area. As such, this paper reports the development of a causal model of variables influencing carbon emissions in dwellings based on mental models of the experts. The methodology for the research in this paper draws its philosophical foundation from the pragmatist research paradigm based on the system dynamics approach. Data for building the initial causal model were collected from the related literature and subsequent interview of the experts through their knowledge elicitation. The final causal model was developed by subjecting the initial causal model to experts' review based on focus group approach by way of mental knowledge elicitation. The findings indicate a population of causal variables influencing carbon emissions in dwellings and show the complexity involved among the variables. The study concludes that the approach used in building the causal model has the capability of improving the accuracy and credibility of the developed causal model.

INTRODUCTION

Over the years, the housing sector of the economy has been at the epicentre of sustainability agenda of many nations considering the enormous amount of energy consumption and carbon emissions attributed to this sector. Report has it that up to one third of carbon emissions of all sectors is attributed to the housing sector (UNDESA, 2010). Considering the devastating effects of climate change, this amount is huge and as such, the need to find means of reducing energy consumption and carbon emissions from dwellings. This decision is in line with the previous conventions on climate change in 1992, 1997, 2009 and most recently, 2015. South Africa is one of the signatories to the agreements reached in those conventions to legally cut down the amount of carbon emissions being generated (SEA, 2015a). For example, South Africa has set ambitious targets to cut carbon emissions by 34% from business as usual by 2020, and by 42% by 2025 through the "intended nationally determined contribution" plan (SEA, 2015b). Reduction of the energy consumption patterns in dwellings

is one of the targets to cut the emission. Many high level studies have been conducted within the South African energy sector as demonstrated by the works of Beute (2010), ERC (2011), Arndt *et al.* (2011), Alton *et al.* (2012), Senatla (2012), amongst others. However, there is limited evidence to suggest that much study have been conducted in the area of energy and carbon emissions reductions within the housing sector in South Africa.

Many studies have established that there is a population of variables influencing energy and carbon emissions in dwellings (Motawa & Oladokun, 2015a; Gram-Hanssen, 2014; Tweed *et al.*, 2014; the CIBSE, 2013; Abrahamse & Steg, 2011; Kelly, 2011; Yun & Steemers, 2011; Isaacs *et al.*, 2010; Moll *et al*., 2005; Bartiaux & Gram-Hanssen, 2005; Bin & Dowlatabadi, 2005; and Hitchcock, 1993). Among those variables according to Hitchcock (1993) are dwelling size, materials, heating system, stock of appliances, dwelling's internal temperature, hot water usage, appliances use, occupants' thermal comfort, occupants behaviour, amongst others. Motawa and Oladokun (2015a) aptly mapped these variables into three systems consisting of the dwelling system, occupants system and environment system. Motawa and Oladokun (2015b) argued that the variables in each of the systems do interact and interrelate in a complex manner and recognised the need for appropriate methodology capable of capturing this kind of complexity.

Importantly, majority of studies within the housing energy and carbon emissions have greatly benefitted from the building physics and numerical simulations considering the amount of hard data collected on individual dwellings as demonstrated in the studies of Mhalas *et al.* (2013), Jenkins (2008), Fung (2003), and Johnston (2003), amongst others.
Those approaches are purely quantitative and deterministic in nature (Oladokun and Emuze, 2018), while in true sense modelling this kind of a system involves capturing both the quantitative and qualitative variables. Often times, however, the qualitative variables do lack empirical data to support the relationships among those variables and this has been reported to pose problems to studies within this research area. As such, this paper reports the development of a causal model of variables influencing carbon emissions in dwellings using the experts' knowledge elicitation approach of the system dynamics modelling method.

RESEARCH METHODS

The research methods used for the study in this paper draws its philosophical foundation from the pragmatist research paradigm based on the system dynamics approach. The system dynamics approach as used in this study has been covered extensively in another study by Oladokun and Emuze (2018). This approach is summarised in Figure 1. As shown in Figure 1, the approach suggests that after the research problem has been adequately and appropriately formulated, the model variables were identified.

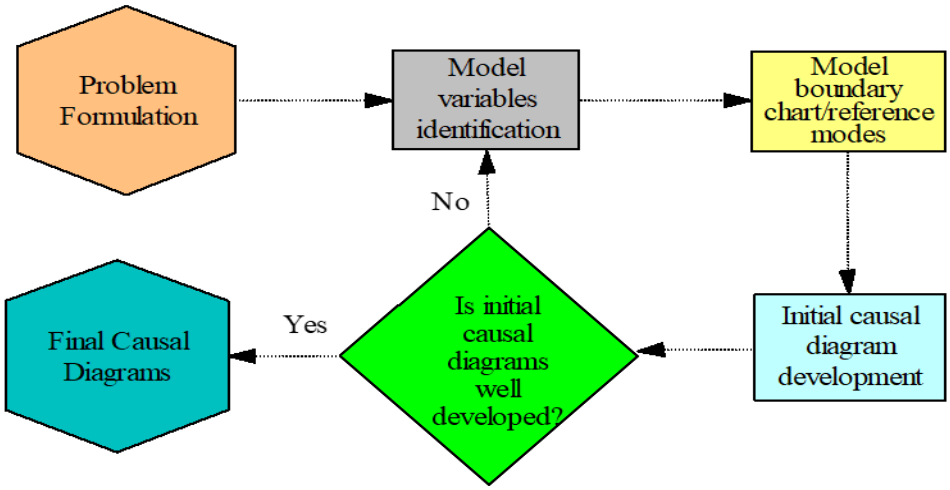


Figure 1. Modelling approach

The identification of those variables were done primarily based on the evidence gathered from the literature by the authors. This forms the basis for creating a boundary for the model. It is important to note that any attempt to model all the variables/activities within this domain is an exercise in futility (Oladokun & Aigbavboa, 2018). As such, the boundary for the study was carefully created in such a way to address the level of aggregation of variables expected by the policy makers. In addition, the reference mode of key variables was given in a bid to serve as the basis for the systems modelling.

After the above activities have been completed, the initial causal model was formulated. This exercise shows how all variables in the model relate with one another indicating their interdependencies and interrelationships. Data for building the initial causal model were collected based on content analysis of extant literature on the subject as well as the authors' ideas. In a bid to verify and validate the initial causal diagrams developed, specifically to find out whether or not they appropriately reflect experts expectations, the causal models were subjected to experts review in the form of experts' knowledge elicitation. The focus group approach was used for the mental knowledge elicitation of the experts that were purposively selected. The experts who participated in the study performed the following tasks (Oladokun & Emuze, 2018):

- Verify the existence of the link between two variables with '1' for 'there is link' and '0' for 'there is no link'.
- Indicate the strength of the link with '3' for 'strong link', '2' for 'reasonable link', and '1' for 'weak link'.
- Verify the direction of link with '+' for 'agree the direction' and '-' for 'disagree the direction'.
- Indicate any missing link(s) with 'Y' for Yes there is link and 'N' for No there is no link.
- Indicate any other variables that would have been included.

A sample of data capturing instrument from the experts is shown in Appendix A. The final causal diagrams were drawn after the feedback from the experts. The initial causal models developed were adjusted and amended appropriately.

SYSTEM CONCEPTUALISATION OF THE VARIABLES INFLUENCING CARBON EMISSIONS IN DWELLINGS

Based on the approach used for the research in this paper as discussed above under the research methods, the following are the findings emanating from the study in the form system conceptualisation of the variables influencing carbon emissions in dwellings.

Model sub-systems

The system conceptualisation of the variables influencing carbon emissions in dwellings was developed using a modular system. As such, the high level model shown in Figure 2 disaggregates the dynamics of energy and carbon emissions into six different sub-systems. The complexity in terms of the interdependencies and interrelationships among the subsystems in the model is well illustrated in Figure 2. The six sub-systems are the population/household module, the dwelling internal heat module, the occupants' thermal comfort module, the climatic-economic-energy efficiency interaction module, the household energy consumption module, and the household carbon emissions module. Importantly, the sub-systems are based on the interaction of the dwellings, occupants and environmental systems.

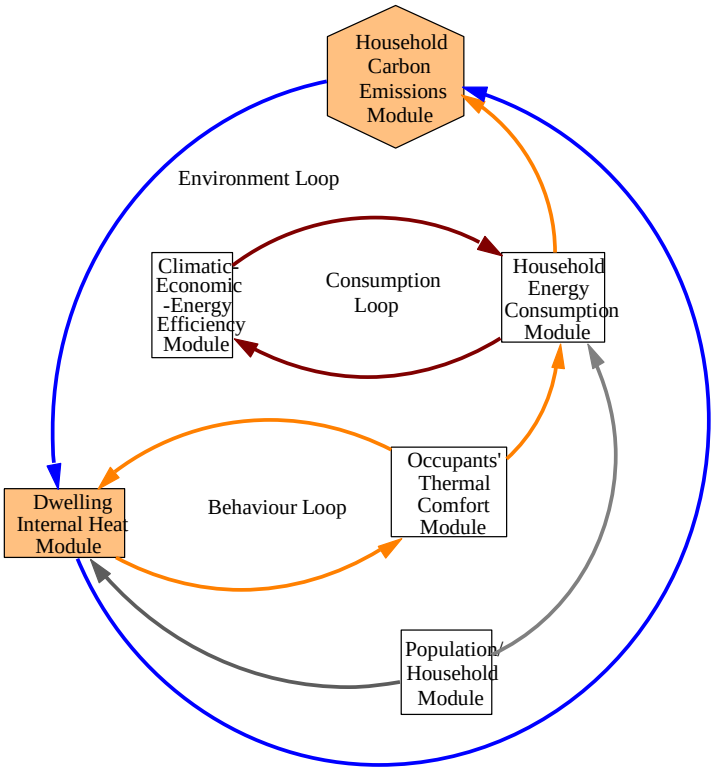


Figure 2. Model sub-systems

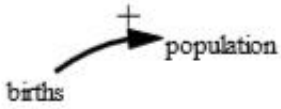
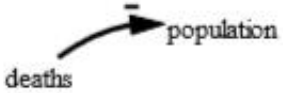
The main causal diagram

This study developed a population of variables influencing carbon emissions in dwellings and this was verified and validated based on knowledge elicitation focus group conducted. One of the outputs evident from the exercise is the fact that all experts that participated in the focus group attest to the fact that there are many variables influencing energy and carbon emissions in dwellings. Their argument was based on the fact that the variables identified are complex when considering the kind of interdependencies and interrelationships existing among them. The causal model was developed based on different sub-systems before being combined together to give a single holistic causal model. For space consideration, the complete holistic causal loop diagram developed could not be presented. However, a part of it is shown in Figure 3. A causal tree shown in Figure 4 was generated from the causal model shown in Figure 3.

In order to be in position to be adequately read the causal model presented in Figure 3, it is important to note that the causal loop diagram was developed based on different variables already identified for the study and indicate how the variables in the model relate with one another. By way of annotation, two variables are selected at a time and the relationship between them is based on the arrow connecting them. The arrows are polarised with a '+' sign depicting a positive relationship, which by implication means that an increase in arrow tail variable would cause an increase in arrow head variable and vice-versa, whereas a '-' sign depicting a negative relationship, which means an increase in arrow tail variable would cause a decrease in arrow head variable and vice-versa (Oladokun & Aigbavboa, 2018). An example of this polarity is shown in Table 1.

It is equally significant to note that the dynamics exhibited by the system under study are achieved based on the feedback loops shown on the causal loop diagram in Figure 3. The feedback loops can either be positive or negative as shown in Figure 3 with '+' or '-' signs inside a circular arrow. Again, the '+' or '-' signs inside a circular arrow depicts a positive feedback loop or what is known as reinforcing loop and a negative feedback loop or what is known as balancing loop respectively. The positive loop means that there will be an indefinite growth of decay within the system, whereas the negative feedback loop tends to balance or stabilise the system over time. In order to achieve the polarity of the loops within the model, the number of negative signs on the variables within the model is counted. An even number of the negatives gives a positive or reinforcing loop, whereas an odd number of the negatives gives the negative or balancing loops.

Table 1. Relationship polarity

Symbol	Interpretation	Mathematics	Examples
	All else being equal, if X increases (decreases), then Y increases (decreases) above (below) what it would have been. In the case of accumulations, X adds to Y.	$\frac{\partial Y}{\partial X} > 0$ In the case of accumulations, $Y = \int_{t0}^{t} (X + \cdots) ds + Yo$	
	All else being equal, if X increases (decreases), then Y decreases (increases) below (above) what it would have been. In the case of accumulations, X subtracts from Y.	$\frac{\partial Y}{\partial X} < 0$ In the case of accumulations, $Y = \int_{t0}^{t} (-X + \cdots) ds + Yo$	

(Adapted from Oladokun & Aigbavboa, 2018)

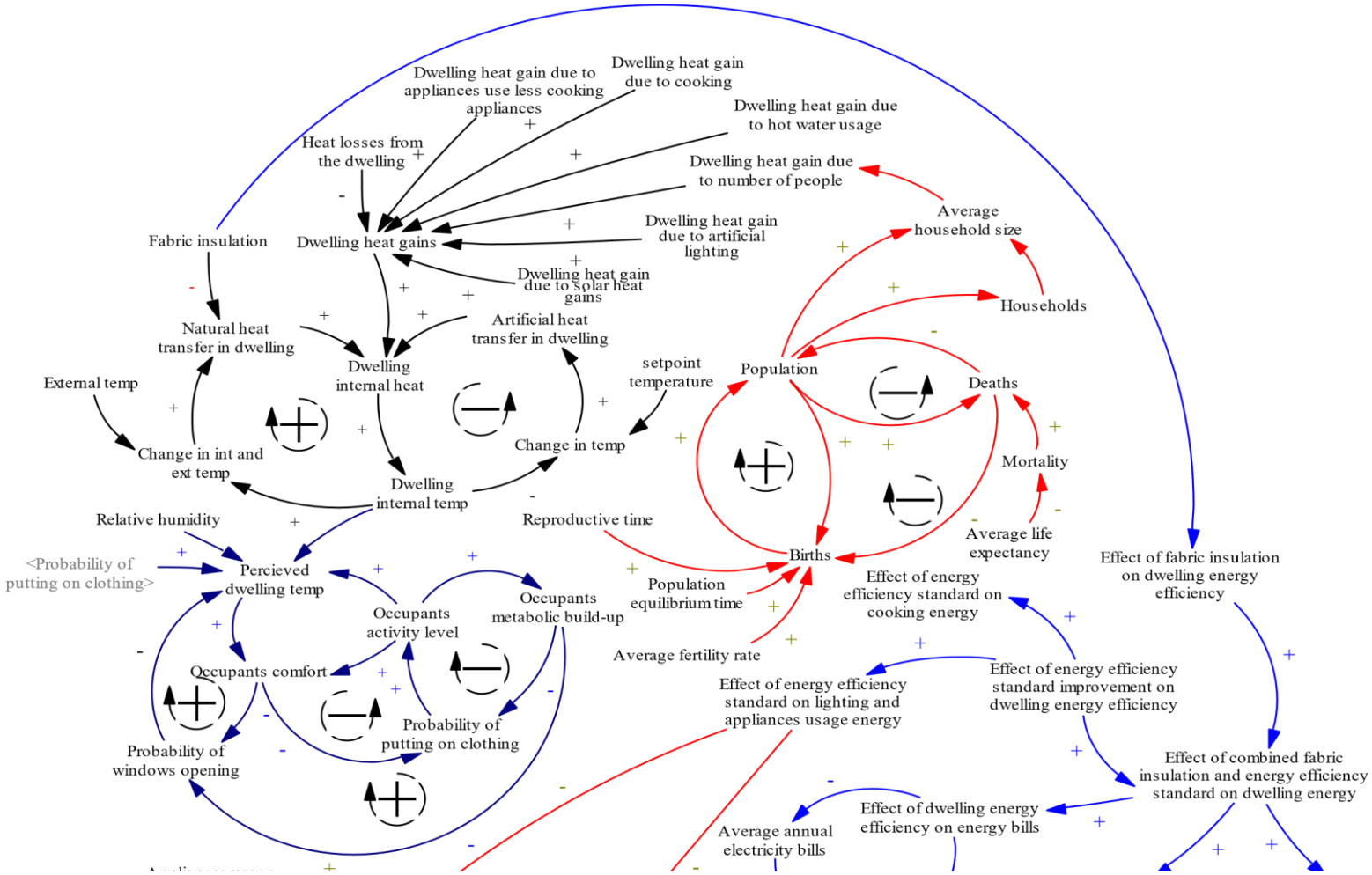


Figure 3. Causal model of variables influencing carbon emissions in dwellings

Figure 4. Causal tree from the causal model of variables influencing carbon emissions in dwellings

RESEARCH IMPLICATIONS

While there are calls for an approach capable of modelling the dynamics of energy and carbon emissions within the housing sector, especially by capturing both the quantitative and qualitative variables, the research being reported in this paper is seen as a response to such calls. This study has demonstrated a modelling approach that transcends beyond only the building physics and numerical simulations by incorporating the variables that are difficult to model quantitatively. Consequently, the value and implications of this study for research and policy are illuminating and profound. The experts' knowledge elicitation technique within the system dynamics approach demonstrated in this study has the capability of improving the accuracy and credibility of the theory that will eventually emanate from the causal diagrams of the interdependencies and interrelationships of variables influencing carbon emissions in dwellings. This is therefore capable of spurring research activities within this research domain. Also, the causal tree shown in Figure 4 demonstrated that the outcome of this study is capable of being used to take informed decisions regarding some policy interventions about energy and carbon emissions in dwellings with the South African housing sector.

CONCLUSION AND FURTHER RESEARCH

The paper has shown that there are many variables influencing energy consumption and carbon emissions in dwellings and those variables do interact and interrelate in a complex thereby constituting a socio-technical problem. The paper has developed a causal model of variables influencing carbon emissions in dwellings within the South African housing sector. The study used the experts' knowledge elicitation technique within the system dynamics approach for the research. As such, the data used for building the causal model emanated from the review of related literature and experts judgement through their knowledge elicitation. The findings from the research showed a population of causal model and tree of variables influencing carbon emissions in dwellings indicating the complexity involved among the variables. The study concludes that the approach used in building the causal model has the capability of improving the accuracy and credibility of the developed causal model. As such, the fully developed model would enable the policy makers take informed decisions regarding some policy interventions about energy and carbon emissions in dwellings with the South African housing sector. Further work for the research would involve translating the developed causal model to stock and flow diagrams and develop algorithms for the relationships among the model variables in readiness for simulation. Afterwards, the output of the simulation run will be presented and the validation of the model conducted appropriately to build confidence in the output.

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Appendix A:

	Link Existence		Link Strength			Link Direction		Missing Link(s)		Remarks
	0	1	1	2	3	+	-	Y	N	
Dwelling internal heat → Dwelling internal temperature										
Dwelling heat gains → Dwelling internal heat										
Natural heat transfer in dwelling → Dwelling internal heat										
Artificial heat transfer in dwelling → Dwelling internal heat										
Fabric insulation → Natural heat transfer in dwelling										
Change in internal and external temperature → Natural heat transfer in dwelling										
Dwelling internal temperature → Change in internal and external temperature										
External temperature → Change in internal and external temperature										
Change in temperature → Artificial heat transfer in dwelling										
Setpoint temperature → Change in temperature										
Dwelling internal temperature → Change in temperature										
Dwelling heat gain due to appliances use less cooking appliances → Dwelling heat gains										
Dwelling heat gain due to cooking → Dwelling heat gains										
Dwelling heat gain due to artificial lighting → Dwelling heat gains										
Dwelling heat gain due to hot water usage → Dwelling heat gains										
Dwelling heat gain due to number of people → Dwelling heat gains										
Dwelling heat gain due to solar heat gains → Dwelling heat gains										
Heat losses from the dwelling → Dwelling heat gains										
Average household size → Dwelling heat gain due to number of people										

Architecture and Design

INFLUENCE OF DESIGN PARAMETERS ON ENERGY CONSUMPTION OF HIGH – RISE RESIDENTIAL BUILDINGS IN DIFFERENT CLIMATE AREAS IN CHINA BASED ON GREEN BUILDING STUDIO

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Keywords: Design Parameters, Energy Consumption Simulation, High-Rise Residential Buildings

Abstract

Reducing building energy consumption is an important task for establishing a conservation-oriented society and therefore realizing sustainable development strategies in China. As energy consumption of residential buildings accounts for a large proportion of total amount in the country, improving the efficiency of energy use of projects of this type becomes increasingly important. To cope with this, the design parameters should be carefully chosen according to the surrounding natural climate during the architectural design stage. In this paper, we established a high-rise residential Revit model and adopted Green Building Studio (GBS) energy consumption simulation software to analyse the influence of four design parameters on the energy consumption of high-rise residential buildings in China. These parameters are the wall material, window material, window-wall ratio and building orientation. The energy consumption includes cooling and heating and overall use. In order to compare different climate areas, we selected five typical cities located respectively in severe cold region (Harbin), cold region (Beijing), hot in summer and cold in winter region (Shanghai), hot in summer and warm in winter region (Guangzhou) and moderate region (Xishuangbanna). Through the horizontal comparisons and in terms of a certain building design parameter, we obtained the difference of its influence on the energy consumption of the high-rise residential buildings in typical cities of different climatic regions. By longitudinal analysis and in terms of a certain typical city of a climatic region, we got the influencing degrees of different architectural design parameters on its energy consumption. This is significant to distinguish the architectural designs in different climate areas. The results show that in severe cold, cold, hot in summer and cold in winter regions, the architectural design should focus on the thermal insulation performance of the exterior wall while in the moderate, hot in summer and warm in winter regions, the architectural design should otherwise emphasize the window-wall ratio size.

INTRODUCTION

Energy is one of the basic needs underpinning the activities of human society. In China, the circumstance is the same. Under the challenge of energy shortages, energy conservation is the key to realize the sustainable development. Building energy consumption accounts for about 1/3 of the total national energy consumption. The energy consumption of buildings includes public buildings and residential buildings. The larger one is the energy consumption of residential buildings. With the advancement of urbanization and the limited natural land resources, more and more high-rise residential buildings have occurred. How to reduce the energy consumption of high-rise residential buildings is a very urgent issue. As the electrical equipment that maintains the indoor comfortable environment consumes a large amount of electricity, it has become the focus of
residential energy-saving [1].

The ability to incorporate climate factors into architectural design and rationally select design parameters instead of using air-conditioning equipment to adjust the indoor climate is not only a need for the development of architectural design theory, but also an effective way to achieve building energy conservation and create a healthy living environment. To integrate climatic factors into architectural design, the first thing to do is to study the difference of influence degree by different design parameters with energy consumption of buildings in different climatic zones. There are many design parameters that affect building energy consumption. However, in related domestic and foreign research, most scholars study the influence of certain building morphological parameters of a certain city on building energy consumption. The relevant studies on the differential effects of different architectural morphological parameters in different climatic regions are insufficient. Above analysis proves the necessity of this study, that is, to explore Influence of building design parameters on energy consumption of high - rise residential buildings in different climate areas This is significant to distinguish the architectural design in different climate areas so that they can be adapted to local conditions and provide scientific basis for realizing the goal of green energy conservation in buildings.

LITERATURE REVIEW AND SELECTION OF DESIGN PARAMETERS

Many scholars have studied the influence of relevant parameters of architectural external protection structure on building energy consumption. Zhang (2014) used Dest software to analyse energy consumption based on the actual energy use model of residential buildings in Shanghai, and concluded that the impact degree of related parameters were ranked as the outer window shade coefficient, the outer wall solar radiation absorption coefficient, the outer wall heat transfer coefficient, the roof solar radiation absorption coefficient, the outer window heat transfer coefficient and the roof heat transfer coefficient [2]. Zhang (2015) applied E-QUEST to carry out energy simulation analysis and concluded that the energy conservation potential and economic benefits of these three energy-saving measures gradually reduced, including changing the type of the outer window glass, increasing the thickness of the outer wall insulation layer, and increasing the thickness of the roof insulation layer [3]. Trisnawan (2018), on the other hand, implemented Ecotect software to study the basic optimal efficiency of the existing buildings on the Depok UI campus, namely to maximize the use of natural resources to reduce the energy consumption of buildings [4]. According to the previous studies, the external wall and the external window are the important factors affecting the energy

consumption. Based on previous research, this paper selects four building design parameters including external wall, exterior window, the window-to-wall ratio and building orientation.

The selection of design parameters

The external wall has a thermal insulation function in winter and summer. The performance of the external wall has a very significant impact on the building energy consumption. Wang (2010) selected 7 typical urban houses in the hot summer and cold winter regions as research objects. He analysed the effect of thermal performance of various components of the window and exterior wall on building energy consumption. It is found that the improvement of thermal performance of external walls brings obvious annual energy-saving effects. Its energy-saving contribution rate ranges from 10% to 20%. The external window's energy-saving contribution rate ranges from 7% to 15% [5].

The exterior window is an important part of the envelope structure. Research shows that the external window area accounts for 25%~35% of the area of the envelope structure. The energy loss accounts for about 50% of that of the entire building envelope structure. The design of the external window meets the requirements of indoor lighting but it is still the weakest link in the building insulation. Wang (2017)found that in the case where the window-wall ratio is completely the same, compared to ordinary hollow glass and ordinary glass, the energy loss of windows made of vacuum glass, plastic steel materials and vacuum coating is relatively smaller [6]. Studies have shown that building energy consumption in the hot summer and cold winter regions is greatly related to the properties of different types of glass, such as heat-absorbing glass, heat-reflecting glass, and Low-E glass [7].

The window-to-wall ratio refers to the ratio of the area of the window opening to the area of the facade. The effect of window-to-wall ratio changes with season, light and temperature. The sensitivity of building energy consumption in different climate areas is different with the change of window-to-wall ratio. In summer, the increase of window-to-wall ratio will increase the energy consumption of air conditioning and refrigeration. In winter, the increase in window-to-wall ratio causes heat loss, but it also increases indoor solar radiation. Zhang (2011) confirmed that when thermal insulation function is good enough, the solar radiation is greater than the loss of heat through windows [8].

The building orientation has a great influence on the solar radiant heat that the building obtains. Hu (2017) used DOE-2 to calculate the energy consumption of typical residential buildings in different orientations [9]. It was analysed that the building orientation had a significant impact on energy consumption in the hot summer and warm winter regions. The building energy consumption of north-south direction was lower than that of the east-west direction, up to 15%.

The selection of representative cities

China has a vast territory and the climate conditions vary greatly. According to “Code for the Design of Thermal Engineering for Civil Buildings”(GB50176), China is divided into five climatic zones, including severe cold, cold, hot summer and cold winter, hot summer and warm winter,

and temperate regions (Figure 1-1). Since these five typical cities to a certain extent represent the climate characteristics of the five climate zones, they were selected to make energy consumption simulation, including Harbin, Beijing, Shanghai, Guangzhou and Xishuangbanna.

Figure 1. Climate divisions of thermal engineering design in China

RESEARCH METHODS

In this research, a high-rise residential building is taken as an example. A high-rise residential building refers to a residential building of 11-30 floors, which is mainly divided into a tower-type high-rise, a plate-type high-rise and a plate-tower combination high-rise, and the relevant parameters of the case building are shown in Table 1. After the case building and related parameters were determined, a case building model was built using Revit as shown in Figures 1 and 2, and then created an energy analysis model. Finally, the energy consumption was simulated in the Green Building Studio.

Through document reading, it is determined that wall materials, window materials, ratio of window to wall, and building orientation are important factors that affect building energy consumption. The control variable method was used to study the influence of different influencing factors on building energy consumption. By changing the location of the building, the impact of various factors in different climatic regions on building energy consumption was explored, and the impact was ranked. Finally, the influence degree of different climatic regions on the energy consumption of case buildings was ranked.

Modelling

This study used the Revit as modelling software, which is one of the most widely used software in China's construction industry BIM system. In this study, a 16-storey dwelling was modelled by Revit. Built a model based on energy efficiency design standards for residential buildings. Each floor of the model has a floor area of 128m^2, a total of 16 floors and a total floor area of 2048m^2. The unit is the common type in the current real estate, which has market three-bedroom, two-bathroom and one-family kitchen and elevators.

Table 1, Architectural Parameters.

Height /m	3.0
Building layers	16
Floor area /m^2	128

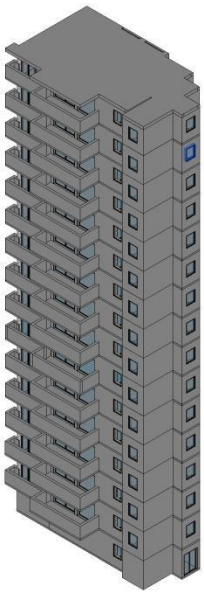


Figure 2. Architectural model

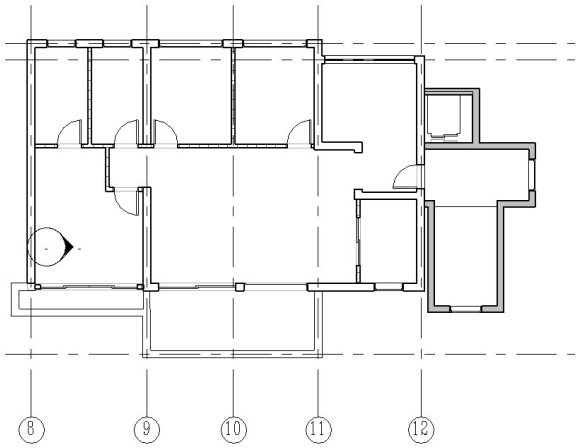


Figure 3. Floor plan 3.2 Simulation

The energy simulation tool used in this study is Green Building Studio. It can establish a structurally correct equivalent thermal model, and can quickly provide feedback on energy deductions in architectural designs.

The program provides energy statistics for the project and suggests improvements to the design based on the local standards of the building type, climate, etc. You can also modify the building design and repeat this process to see the impact of building changes on building energy efficiency.

Before the energy simulation of the case building, the form material was initially set to Double Clear glass(U=0.35 ; SHGC=0.67 ; Tvis=0.72). In recent years, low-e glass has been applied due to its low radiation and energy saving properties. Therefore, the study changed the window materials to Monolithic Clear Low-e and Insulated Blue Reflective Low-e to observe changes in building energy consumption.

The building orientation is initially oriented at 0° (orthonormal orientation) in GBS. This study uses a 30-degree gradient to analyse the change of building energy consumption when building orientations is +30, +60, +90, +120, +150, +180, -30, -60, -90, -120, and -150.

When setting the initial parameters of the building, set the exterior wall material to 8in Concrete Wall with Poured Cores. According to the different requirements of external wall thermal insulation, the wall material was changed to Metal Frame Wall with Super High Insulation and Insulated Concrete Form (ICF) Wall, 12''thick form to observe changes in building energy consumption.

The ratio of window to wall is one of the factors that affecting the energy consumption of buildings. In this study, the proportions of the four walls of the building were adjusted to 15%, 30%, 40%, 50%, 65%, 80%, and 95% to obtain energy consumption under different ratio of window to wall.

RESEARCH RESULTS

Window-to-Wall Ratio

This paper conducted simulation under the window-to-wall ratio of 15%, 30%, 40%, 50%, 65%, 80%, and 95%, working out total annual energy consumption (kw.h), heating energy consumption in winter (kw.h) and cooling energy consumption in summer (kw.h) under different window-to-wall ratio.

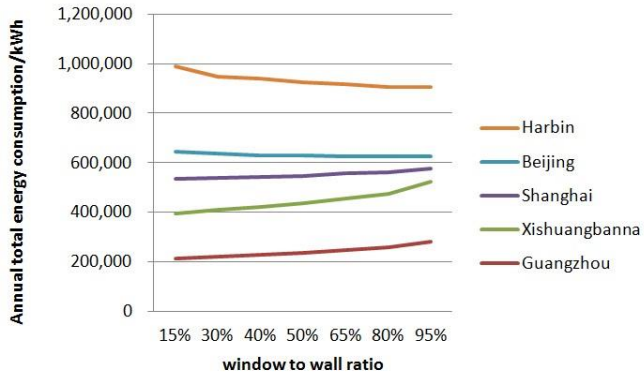
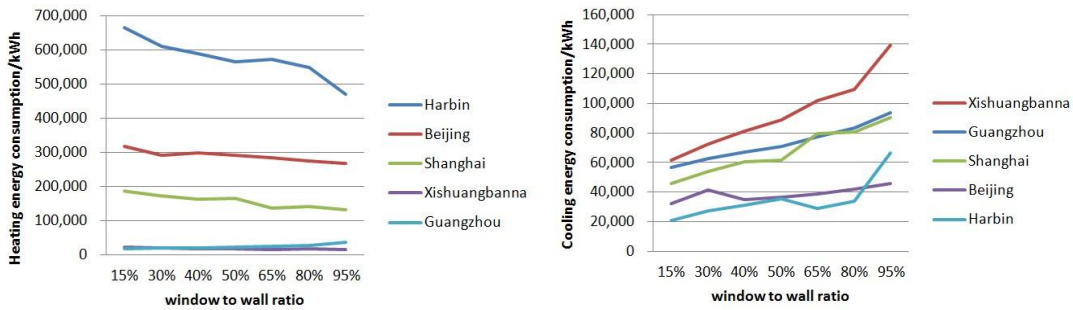


Figure 4-1. Annual total energy consumption varies with window to wall ratio



(a) (b)

Figure 4-2. Heating and cooling energy consumption varies with window to wall ratio

From Fig.4-1 we can learn that the total annual energy consumption of buildings in Harbin and Beijing show a downward trend with the increase in window-to-wall ratio. The total energy consumption of buildings in Shanghai, Xishuangbanna and

Guangzhou rise with the increase in window to wall ratio. Comparing Fig.4-2(a) and (b), we can see that the window-to-wall ratio has a greater effect on cooling energy consumption. The main reason is that in summer, the larger the window to wall ratio, the greater the amount of indoor and outdoor heat transfer. At the same time, the amount of radiation entering the room increases, which adds the cooling load in the room. While in winter, a part of heat loss from indoor and outdoor heat transfer can be compensated by the heat from the solar radiation in the room. Therefore, the unit energy consumption of heating changes more slowly than cooling.

In hot summer and warm winter area and temperate area, the change of window-to-wall ratio has much greater effect on cooling energy consumption than on heating energy consumption. Therefore, under the premise of adequate indoor lighting and ventilation, it is necessary to lower the window-to-wall ratio as much as possible; in hot summer and cold winter area, the heating energy consumption reduction caused by changes of window to wall ratio is greater than the cooling energy consumption increase. As a result, the window-to-wall ratio can be appropriately increased for aesthetic demands; in cold area, the change in window-to-wall ratio has a greater impact on the heating energy consumption. Therefore, cold area can also increase the window-to-wall ratio for aesthetic requirements. In severe cold area, heating energy consumption decreases significantly with the increase of window-to-wall ratio, so under the premise of good thermal performance of windows, large windows can be used to lead solar radiation into the room.

Exterior Window Glasses

This paper separately simulates the energy consumption of insulated blue reflective low-e, monolithic clear low-e and double clear glass, obtaining different window glasses form's consumption.

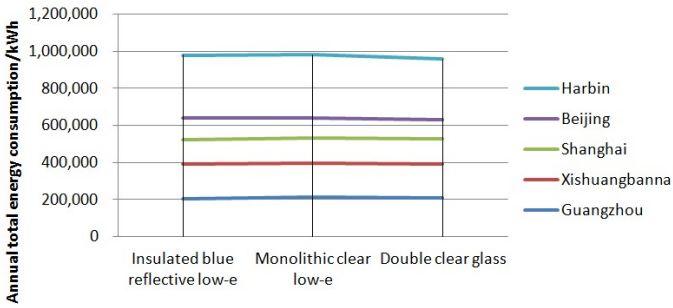
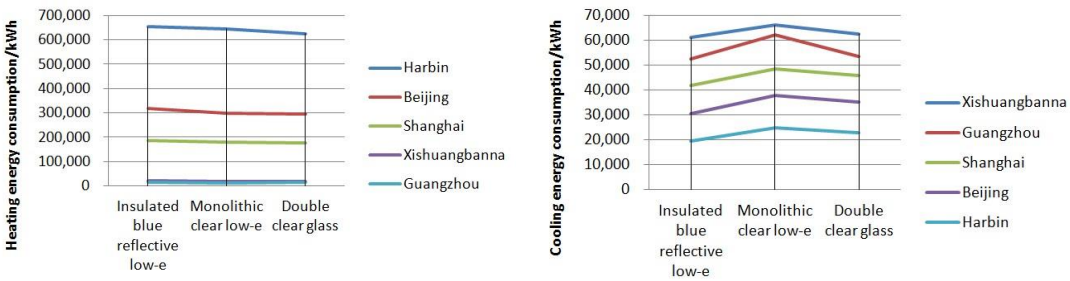


Figure 4-3. Annual total energy consumption of different window glasses



(a) (b)

Figure 4-4. Heating and cooling energy consumption of different window glasses

In general, the total energy consumption of the five representative cities are not particularly sensitive to changes in the types of window materials. The thermal insulation performance of monolithic clear low-e glass is the worst of the three, so it is not suitable for the warm area, in which cooling energy is the majority; Double clear glass has poor thermal insulation properties compared to insulated blue reflective low-e, but has better heat preservation properties and is suitable for cold area; Insulated blue reflective low-e is suitable for warm area. In short, cold and severe cold areas should choose heat preservation material. While in warm area, hot summer and warm winter area, better-insulated material should be selected.

External Wall Type

The initial set of exterior wall is the 8in concrete wall with poured cores that is more common in engineering, and the contrast group is a metal frame wall with super high insulation and 12in insulated concrete form (ICF) wall.

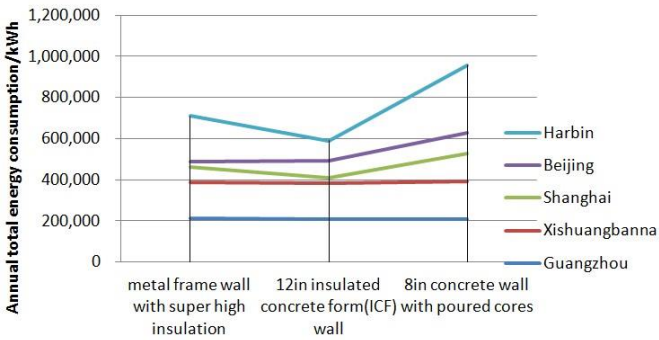
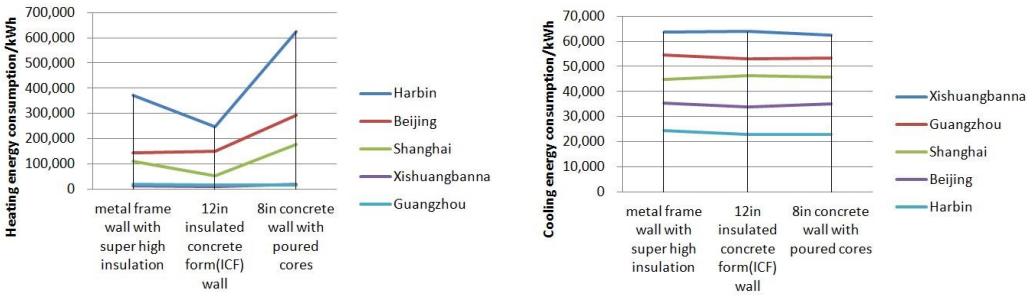


Figure 4-5. Annual total energy consumption of different wall type



(a) (b)

Figure 4-6. Heating and cooling energy consumption of different wall type

Fig.4-5 shows clearly that changing the wall material has no significant impact on the total energy consumption of buildings in Guangzhou and Xishuangbanna, but has significant impact on buildings in Harbin, Beijing, and Shanghai. Among them, the change in Harbin is the most obvious.

Fig.4-6(a) and (b) illustrate that in colder region, the energy consumption of building heating is affected more by the thermal insulation performance of the wall. The reason is that the winter

temperature difference between indoor and outdoor in cold area is extremely huge, so the heat transfers much faster. Therefore, the thermal insulation performance of the wall is particularly important. In hot summer and warm winter area, the temperature difference between indoor and outdoor is small in winter, so the heating energy consumption is not so sensitive to the changes of the wall type; Regardless of the area, the summer temperature difference between indoor and outdoor are not much large, so the cooling energy consumption is not so sensitive to changes in the thermal insulation properties of the envelope structure. Therefore, attention should be paid to the thermal insulation performance of wall in severe cold area, cold area and hot summer and cold winter area, while the hot summer and warm winter area and warm area can select the wall material and thickness from the perspective of economic efficiency.

Building Orientation

The building orientation is initially oriented at 0° (due North) and the building energy consumption is analysed with an orientation gradient of 30 degrees.

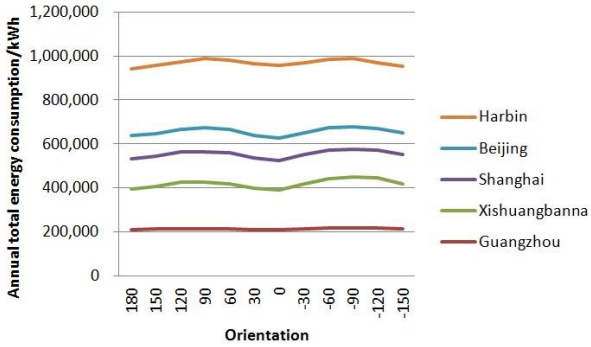
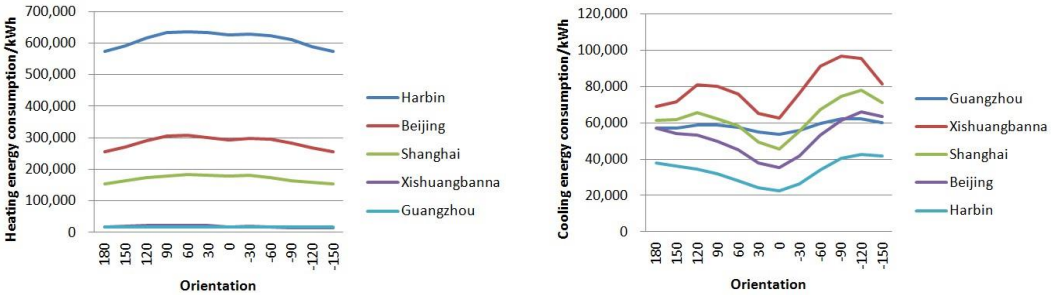


Figure 4-7. Annual total energy consumption of different orientation



(a) (b)

Figure 4-8. Heating and cooling energy consumption of different orientation

It can be seen from Fig.4-7 that regardless of the area, the total energy consumption of building faced north-south is relatively low, and the total energy consumption of east-west facing is relatively large.

Fig.4-8(a) and (b) illustrate that the changes of heating energy consumption of Harbin, Beijing and Shanghai is more obvious with orientation than in Xishuangbanna and Guangzhou; the cooling energy consumption of each region changes significantly with the orientation. For the

hot summer and warm winter area, the orientation of the buildings should be in the north-south direction, but the range can be wider. For the warm area, it is better to consider the orientation impact on cooling energy consumption. Although the cooling energy consumption is relatively more sensitive in cold area, the proportion of heating energy consumption is relatively large. After comprehensive consideration, the north direction should be selected. For buildings in severe cold area whose heating energy consumption are more sensitive, south orientation should be selected for comprehensive consideration.

Vertical Comparison

The impact of four different factors on building energy consumption in each region is analysed above. In the following analysis, the impact of changes in four factors on energy consumption in the same region will be compared.

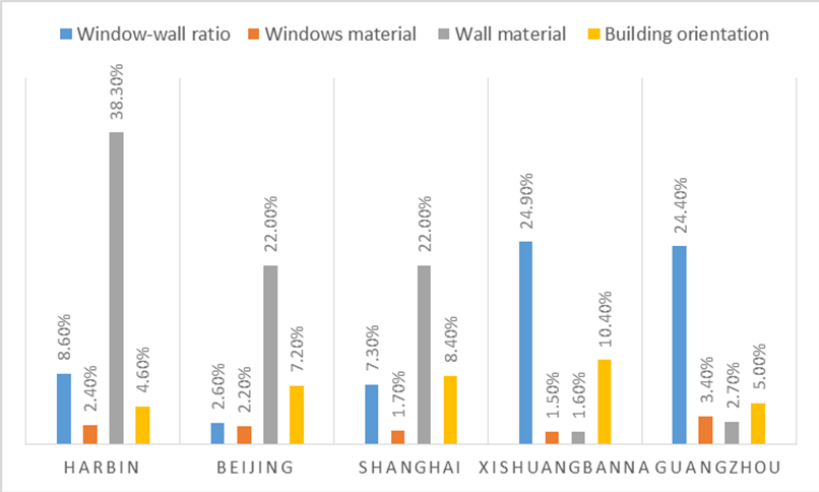


Figure 4-9. Vertical comparison

In general, the total energy consumption in severe cold area and cold area represented by Harbin and Beijing is higher than that in other climatic regions. The energy consumption of buildings under different regions varies approximately with the same factors, but the differences exist between sensitivities of different regions. For severe cold area, the envelope material has the greatest impact on its energy consumption, and window to wall ratio is the second highest; In cold area, the envelope material has the greatest impact on energy consumption among the four factors, and the influence of building orientation cannot be ignored; For hot summer and cold winter area, the least influential factor is window glasses, and the enclosure structure materials still dominate. At the same time, both the window to wall ratio and the building orientation have a certain influence; For temperate area, the effect of window to wall ratio and building orientation on energy consumption is significantly higher than that of the window glasses and the envelope materials; For hot summer and warm winter area, window to wall ratio has significantly greater impact than other factors.

To sum up, the building energy consumption in severe cold area, cold area and hot summer and cold winter area are most sensitive to the building envelope materials. Therefore, the heat preservation performance of the enclosure structure should be considered particularly. The energy consumption of buildings in temperate area and hot summer and warm winter area is most sensitive to window to wall ratio. Hence, in these regions, the window to wall ratio should

be considered particularly. In the specific architectural design, it is necessary to optimize economic factors and social factors to comprehensively design environmental-friendly and energy efficient green buildings.

DISCUSSIONS

Compare the research results with the expected results and it is found that : As the window-wall ratio increases, the total energy consumption and summer cooling energy consumption in the regions represented by Shanghai, Xishuangbanna, and Guangzhou will increase, while the cooling energy consumption in the regions represented by Harbin and Beijing will decrease. Winter heating energy consumption and total energy consumption show a downward trend. This is consistent with the research findings of Zhang (2011) [8]. She verified that when thermal insulation function is good enough, the solar radiation is greater than the loss of heat through windows.

Through the analysis of the window glass and the wall type, it can be concluded that in colder areas, the design of buildings should emphatically take the thermal insulation performance of the exterior enclosure into consideration. While in the hotter areas, the thermal insulation of the exterior enclosure should be paid more attention. The previous study mainly focused on the analysis of the buildings in the hot summer and cold winter regions, and lacked analysis of the building energy consumption in cold winter regions. This study just compensates for this deficiency and selects representative urban dwellings for different climatic regions, comprehensively analyses the impact of enclosure structures on building energy consumption under different climatic conditions.

The study concludes that the total energy consumption is relatively low under the North-South orientation conditions. Comprehensive consideration of the influence of regional climate can flexibly adjust the building orientation and achieve the best building energy saving. This coincides with the findings of Hu (2017) [9], who found that the energy consumption of the buildings in the north-south orientation is lower than that in the east-west orientation. In addition, this paper takes a gradient change of the building orientation, and analyses the energy consumption from the aspects of cooling and heating, respectively, to obtain a graph showing the changes of building energy consumption with the changes of building orientation under different climatic conditions.

CONCLUSIONS

The paper selects four factors of window -wall ratio, window glass, wall type and building orientation as independent variables, and uses the research method of control variables to analyse. GBS is used to study the effect of architectural form parameters in different climatic regions on building energy efficiency innovatively. The study compares horizontal and vertical directions respectively, and proposes scientific and comprehensive energy-saving suggestions. The most significant factor affecting the building energy consumption in the regions represented by Harbin, Beijing, and Shanghai is the wall materials. The energy-saving design of

buildings should focus on the insulation properties of wall materials. At the same time, Harbin should take the window-wall ratio into account, and the buildings in Beijing and Shanghai should be oriented north-south. The most significant factor affecting the building energy consumption in the areas represented by Xishuangbanna and Guangzhou is the window-wall ratio, therefore appropriately reducing window-wall ratio can achieve better energy-saving effect. The research also shows that architects should pay enough attention to regional factors and different influencing factors in energy-saving designs, and give full play to the subjective initiative, comprehensively consider the various design projects of the construction project in the aspect of architectural design and layout, so as to make full use of the energy-saving potential of the building and further promote building energy conservation.

ACKNOWLEDGMENTS

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IDENTIFYING THE RELEVANT COMPLIANCE CONSIDERATIONS RELATED TO THE REFURBISHMENT OF EXISTING BUILDINGS IN SOUTH AFRICA

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Keywords: sustainability, legislation, old building stock, refurbishment

Abstract

The construction industry is known to consume significant resources and contribute to the transformation of cityscapes, urban and ruralscapes. However when buildings are completed they still contribute to environmental degradation by their high energy consumption, the growing global environmental awareness is putting pressure on new buildings to be designed in such a way as to conserve energy. In South Africa in line with what is happening globally new buildings are required to comply with environment stipulations to enhance energy sustainability and reduce the impact of new stock on energy consumption. The old stock remains the sticking point as the buildings were delivered before the current legislative pronouncements. It has been observed that even the refurbishment of these buildings is not yielding sustainable performance as the upgrades are purely aesthetical cosmetic upgrades. The Promulgation of the South African National Accreditation System (SANAS) seeks to address this challenge through the South African National Standard (SANS) 1544, which is the basis for the issuance of certificates for compliant buildings. The Research utilized four (office blocks) public case studies of refurbished projects in Johannesburg to understand the level of appreciation and understanding of the legislative prescriptions. Contractual documents were perused through and interviews were held with client representatives and thematic analysis revealed two main observations. The private sector clients are mostly environmentally conscious as this is considered to be an image issue whereas with the government officials there was a very reasonable percolation of the ideals of SANAS. It was observed that despite the noble aspirations by the government a structured approach is needed to bring about the necessary buy-in from all sectors and that there should be a proper implementation of the necessary punitive measures.

INTRODUCTION

The construction industry has had a boom over the last few years. This is both good news and bad news, good for the economy as the ripple effect of the construction activity can resuscitate an ailing regional and national economy. However the construction industry and the materials industry which support it are the major global exploiters of natural resources, both physical and biological (Spence & Mulligan, 1995). The construction industry has been identified as a chief contributor to the unsustainable development currently occupying the minds of decision-makers around the world. The issue of sustainable development which encapsulates the notion that the depletion of the resources and biological systems should be avoided, in order to ensure

that future generations are not impoverished by current activities is rightfully a talking point globally. The Biosphere has limits to the level of human economic activity that it can handle and although this has to be protected the by improving technology and social organization to create a new era of economic growth. In the US alone the construction industry accounts for about 25% of the non-industrial waste generation a year. Furthermore the construction industry changes the surface of the land due to clearing of vegetation and excavation. The materials used in construction account for large quantities of CO2 emissions due to high contents of embodied energy content (Initiafy, 2017). Although the debate is mostly concentrated on dealing with new buildings and ensuring that they assist with sustainability the old stock of buildings is still a problem since they were constructed when the populace was not generally sensitised on environmental vulnerabilities.

The purpose of this study was to identify the contextual barriers and opportunities pertaining to sustainable refurbishment of existing office buildings utilized by the public sector in South Africa. In most cases refurbishment is driven by cosmetic upgrade initiatives. However the existing building stock offers an opportunity to improve building performances and reduce negative impacts on the environment. The main intention was to highlight this potential by looking at barriers and present the opportunities pertaining to the sustainable refurbishment of existing buildings utilized by the public sector office in inner city area of Johannesburg, in South Africa.

LITERATURE REVIEW

Over their lifecycle, construction projects consume significant resources and contribute to the transformation of cityscapes, urban and rural landscapes. As a result they have significant impacts on the environment, human health as well as economic consequences (ISO, 2008). *ISO 15392, Sustainability in building construction - General Principles,* lists five reasons why the building and construction sector is of significance for sustainable development. One of these reasons is because the built environment has considerable opportunity to show improvement relative to its social, environmental and economic impacts (ISO, 2008).

The energy consumption of the existing building stock will continue to exceed the energy consumption of new buildings till at least 2050. This date is based on scenarios used in South Africa that suggests that overall reductions in energy use achieved from existing buildings would only amount to approximately 10% (Milford, 2009). Efficiencies of approximately 40% to 50% could be achieved in new buildings in the commercial sector and 30% to 40% in the residential sector (Ibid.). It is therefore important to focus on improving the energy performance of the existing building stock as well as that of new buildings (DoE, 2012).

The Department of Energy (DoE) of the government of South Africa released the first National Energy Efficiency Strategy (NEES) in 2005. The NEES aimed to commit to energy efficient strategies by reducing environmental impacts. Reduction targets were identified as per Table 1 below (DoE, 2016).

Table 1. Improvements in energy intensity (2000-2012) compared to the 2005 targets (DoE, 2016)

Sector	2015 Target (based on 2000 baseline)	Performance to 2012
Economy-wide	12%	23,7%
Industry	15%	34,3%
Residential	10%	28,2%
Commercial & Public	15%	0,3% (electricity only, 2003-13)
Transport	9%	14,1% (reduction in sector-wide energy intensity)
Power Sector	15%	Probably achieved, although no baseline against which to measure percentage savings

Although the commercial and public building sector contribute to only 8% of the national energy usage, there is the potential to translate into a significant saving in energy (DoE, 2012). Energy consumption within the public sector is expected to increase significantly in 2030 when compared to 2012 consumption levels. These increases can be mitigated by sustainable interventions and refurbishments. The largest potential saving would be from the new stock of commercial buildings as well as the existing stock (DoE, 2016).

Refurbishment of Existing Buildings

Among the many ways that sustainability has been defined, the simplest and most fundamental is: "the ability to sustain" or, alternatively, "the capacity to endure"" (SustainAbility, 2010). Sustainable development has been described as meeting the needs and aspirations of people in a manner that does not compromise the ability of future generations to meet their own needs and aspirations (DPW, 2014). The primary facets of sustainability are interdependent: namely; environmental, social and economic facets (ISO, 2008). The Green Building Policy Draft 3 in South Africa also refers to environmental sustainability, social sustainability and economic sustainability being the three components of sustainable development (Nordic Innovation, 2014; Department of Public Works, 2014).The main objectives of sustainable design include reducing or completely avoiding the use of critical resources; water, energy and raw materials, to minimize the negative effects on the environment caused by buildings throughout their life cycle and to create comfortable and safe environments (Hesbacher, 2016). Sustainable buildings can be defined as those that fulfil the necessary performance requirements based on their intended use in an efficient and economical way with minimal negative effects on the environment (Nordic Innovation, 2014).

Climate change and other risks caused by rapid urbanisation are negatively affecting attempts at sustainable development (IFC, 2014). Rapid urbanization in the world's most populous countries requires sustainable buildings to ensure sustainable development. Currently almost half of all the resources consumed globally are used in construction and 40% of the energy generated globally is used for building related functions. Buildings are responsible for 30% of worldwide greenhouse gas emissions and this figure will rise as populations continue to migrate to cities. The built environment consumes 40% of global material production and is responsible for 65% of municipal solid waste generation (Aye, 2010). The Intergovernmental Panel on Climate Change (IPCC, 2007) suggests that the building sector has shown the potential for delivering the greatest reductions in emissions at little or no costs. Based on this data the property industry may be well placed to deliver long term sustainable improvements as well as influence and create behavioural change. Because of the huge negative environmental impacts caused by buildings, improving the performance of buildings appears to be an avenue that deserves attention. If no significant change is effected to the manner in which buildings are designed, constructed and maintained then greenhouse gas emissions are set to double in 20 years (UNEP-SBCI, 2009). Ten years after the Earth Summit in Rio de Janeiro, the World Summit on Sustainable Development took place in Johannesburg, South Africa in 2002 and global commitment to sustainable development was reiterated. The Johannesburg summit marked a further expansion on the globally accepted and standard "Brundtland definition" of sustainable development by introducing the widely used three pillars of economic, social and environmental development. The Johannesburg declaration highlighted the inter-relationships and inter-dependencies of the three facets of sustainability (Kates, et al., 2005).

The South African Context

The total building stock in South Africa can be expected to double by 2050 based on historical trends and anticipated government investment programmes. If nothing is done to address CO_2 emissions this would result in a twofold increase (Milford, 2009). Energy efficiencies between 40 – 50% and 30 – 40% could be achieved in non-residential and residential building, respectively. A challenge noted is the ability to effect changes in existing buildings in South Africa and scenarios used indicate that existing buildings could still be responsible for 50% of the emissions in 2050 (ibid.). World Green Building Trends 2016 results indicate that South Africa is one of the few countries where the highest percentage of the respondents expect to be doing green renovations in the next three years. Forty six percent of respondents in South Africa expect to be completing green refurbishments and in this category the global average is 37% (Jones & Laquidara-Carr, 2016). Again this demonstrates South Africa's leadership attitude in the sustainable refurbishment arena.

Revising the building regulations to address the energy efficient refurbishment of the existing building stock is the most effective and direct manner of achieving a more sustainable built environment. Government incentives would support and address the voluntary deep energy efficient refurbishment required (Wafula & Talukhaba, 2010). The success of the legislation is dependent on compliance of the construction industry and this result in more efforts on training and awareness and the role of local authorities and building inspectors (ibid.). The pending energy performance certification regulation will require all South African government owned and leased buildings to disclose and prominently display the buildings energy

performance through an energy performance certificate (Hayes, et al., 2016). South African National Standards (SANS) 1544:2015 Energy performance certificates for buildings, will address refurbishment of public sector buildings as mandatory. This will eventually filter through to the private sector. It is envisaged that change of ownership may be a mechanism that supports the use of SANS 1544 in the private sector (DPW, 2014). This is supported by the Construction Industry Development Board's (CIDB) Dr. Rodney Milford who said, "The idea is that the Energy Performance Certificates (EPC) will have to be displayed on state owned buildings with the intention that the regulation be extended to cover the commercial sector by around 2020" (Hayes, et al., 2016). Once the performance of the existing building is measured and verified, appropriate interventions can be considered and implemented to improve the performance. According to Hayes (2016) understanding the buildings performance is the first step in the energy efficiency journey. The later drive to retrofit the building into a more energy efficient one is the ultimate goal because as with all things, if you can't measure it you can't manage it (Hayes, et al., 2016).

The South African Bureau of Standards (SABS) Standards Division develops and issues national standards, where the term "standard" is used generically to refer to a specification, code of practice or standard method. The 10400 suite of documents covers provisions for building site operations and building design and construction that are deemed to satisfy the provisions of the National Building Regulations (SABS Standards Division, 2009). South African National Standard (SANS) 10400-XA: Energy usage in Buildings is a minimum standard for new buildings as well as refurbishments where submission of building plans to the local authority is required. SANS 204: Energy Efficiency, is a voluntary standard that is also a minimum requirement for consideration for Green Star South Africa (GSSA) certification. Legislation and regulation is the key driver for transformation of the development of the built environment. The Department of Public Works (DPW) *Green Building Policy* sets out the policy for applying sustainable development principles and technologies to its own building portfolio. The DPW will provide leadership in the procurement and operation of green buildings within South Africa with the organ of state. This will occur through the DPW Green Building Policy. As described above, the adoption and implementation of EPC, SANS 10400:XA and SANS 204 will be reinforced by the DPW. This will be supplemented by Eco-Labelling programs, Green Building Rating, Water Performance Certificates (WPC) and Energy, Water and Waste Management Plans (EWWMP) (DPW, 2014). The DPW, through the implementation of the Green Building Policy aims to support sustainable development in South Africa, job creation and the development of green jobs and roles, improved working and living conditions, the development of cost effective solutions and the efficient use of resources through the lifetime of the building (DPW, 2014).

The Green Building Council of South Africa

The Green Building Council of South Africa has developed the Existing Building Performance Tool which is designed to cater for the existing building segment. Projects are measured, rated and rewarded for their promotion and implementation of green building practices, programs and technologies. This tool makes it possible for owners of existing buildings to receive Green Star South Africa rating. This supports the Green Building Council of South Africa's objective of promoting sustainable development and facilitating the transition of the South African property industry toward a more sustainable approach to developing the built environment (GBCSA, 2016). According to the 50 Certification Publication, new buildings in South Africa

amount to 2% of the building stock while the remaining 98% is existing buildings (GBCSA, 2014). Currently there are 18 projects registered for Existing Building Performance rating on the GBCSA website (GBCSA, 2016). In addition to sustainable design concepts for new buildings, sustainable refurbishment of existing buildings is preferred and recommended when compared to building new facilities. Sustainably refurbishing existing buildings can be more cost effective than building a new facility. Further one could expect a decrease in operation costs and environmental impacts as well as increased building resiliency (Babangida, et al., 2012) (GBCSA, 2016).

Technology, Well-being, Occupant Comfort

The business case is not very compelling if the primary discussion regarding the refurbishment of existing buildings is energy cost savings alone (Newman, 2012a). Green building is also being driven by a sense that these buildings will improve and enhance productivity. This is being viewed as more valuable than the savings gained from decreased utility bills (Newman, 2012a; Newman, 2012b). Occupant comfort, well-being and productivity are becoming key considerations in the design and construction of buildings.

New technologies and methodologies in design and construction are yielding greater efficiencies and support sustainable habitat. There is a growing trend regarding occupant comfort and increased productivity and user satisfaction. Kaderják, et al., (2012), states that investment in building refurbishment brings additional benefits including health and social effects. Sustainable refurbishment approaches has multiple benefits including increased marketability, staff retention, and decreased churn, less volume to landfill and therefore more profitable assets and facilities. Indoor environment quality and acoustic comfort is receiving greater attention than previously and this is apparent in current Green Star South Africa rating tools (GBCSA, 2016). The International Well Building Institute has published the first standard of its kind that focuses solely on the health and well-being of builings' occupants. Buildings should not only be better for the planet but also better for the people. Human health and comfort should be elevated to the forefront of building practices (International Well Building Institute, 2016).

When buildings are sustainably improved, it is expected that their maintenance costs will be considerably reduced. There is a growing perception that the cost of sustainably refurbishing an existing building is far cheaper than demolishing existing and developing a new building (Adeyemi, et al., 2014). Demolition is regarded as an environmentally unfriendly process. Improving an existing building generates less waste, uses less material and energy when compared to demolition and new build. There are significant benefits across the three facets of sustainability of improving an existing building sustainably in comparison to demolition. Included benefits are; reduced waste to landfills, reuse of materials, reduced transportation and transportation costs, maintaining community infrastructure and developing local skills (Ibid.).

A gap noted in the literature is that the focus is primarily energy efficiency and no significant attention to waste and water management. The identification of the contextual barriers and opportunities pertinent to sustainable refurbishment of existing buildings should include all aspects of sustainability pertaining to people, planet and prosperity. This should be addressed through a "circular economies" approach. A gap identified by Wafula & Talukhaba in 2010 was

the lack of cost estimation data for energy efficient retrofits when compared to traditional cosmetic upgrades. Financial experts don't view energy efficient upgrades as investments but rather as measured expenses much like consumables.

METHODOLOGY

This research is by its nature mostly qualitative although the use of quantitative elements of data will make it a mixed method. According to Maxwell (2012) to design a qualitative study, one cannot just develop (or borrow) a logical strategy in advance and then implement it faithfully. Qualitative research design, to a much greater extent than quantitative research is a "do-it-yourself" rather than an "off-the-shelf" process, one that involves "tacking" back and forth between the different components of the design, assessing their implications for one another. It does not begin from a predetermined starting point or proceed through a fixed sequence of steps, but involves interconnection and interaction among the different design components (Maxwell, 2012). The study is embedded in cases so it will take a case study approach. A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real life context especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2009). According to Merriam (2009), case studies are anchored in real life situations. A case study approach results in a rich and holistic account of a phenomenon. It expands the researcher's experiences by offering insights and highlighting meanings. The insights could lead to future research and therefore the case study research method plays an important role in advancing a field's knowledge base (Merriam, 2009). Case study research uses quantitative or qualitative research and often adopts a mixed method approach to fully understand the dynamics of the case (Saunders, et al., 2016).

This study addressed three cases; leased buildings occupied but not owned by government, buildings occupied and owned by government and government owned buildings that are to be refurbished through a public private partnership model. Data collection methods included fieldwork visits, observation, interviews and document analysis (Goodrick, 2014). Some of the information was gathered from user/occupants who provided feedback through interviews. Of the three types of interviews which are structured, semi-structured and unstructured; Semi-structured interviews offer a flexible balance between structured and unstructured. It provides the opportunity to probe deeper where required as well as redirect the engagement where required (Saunders, et al., 2016). It is for this reason that these were deployed in this study. Semi-structured interviews with industry experts were required to present a first-hand view of the current context and the framework for change together with implementation strategies. Data is more usable when it is arranged in categories. The research question and sub questions informed the categories (Saunders, et al., 2016). Data collected from the case studies was analysed using content analysis. Content analysis is effective in using an entire dataset to identify underlying themes that may be presented through the data. This is a similar approach to that of Masrom (2017).

RESULTS AND DISCUSSIONS

Case Studies

1) The Kopanong Precinct: The project aims to create economies of scale in all areas for government departments. The precinct will lie within a demarcated area within the CBD. The project will enable increased interdepartmental efficiencies through communication leading to increased service delivery. An added advantage is the urban regeneration that this project presents and stability of occupancy which comes with ownership (GDID, 2015). The project is a PPP between Gauteng Department of Infrastructure Development (GDID) and the Gauteng Funding Agency (GFA) which involves the refurbishment of 19 buildings in the CBD of Johannesburg, the Capex costs will be borne by with the government contributing annual unitary payments for 22 years.

Figure 1: Aerial location view of Kopanong Precinct (The Heritage Portal, 2017).

The first phase involves the refurbishment of abandoned buildings and this would require at least 2 years. Phase 2 would be the refurbishment of occupied buildings. The extent of the project spans 350 000 square meters GBA and 200 000 square meters GLA. This project will affect more than 14 government departments and 12 000 people within the precinct. Amenities include an events plaza, activated edges containing restaurants, cafes and bars (The Heritage Portal, 2017). The project will range between 5 and 7 clusters and each cluster will be high value in the range of several hundred million rands.

2) The Corner House: Known as The Corner House, this case study is located at 63 Fox Street in the Johannesburg CBD. The building is owned by the government was built in 1965 and has a GBA and GLA of 28 566 m^2 and 16 393 m^2 respectively. The building is now accommodating administrative head office functions. The scope included the ground floor refurbishment and floors 13 to 16 also requiring a refurbishment to accommodate the 400 department employees. These included GDID employees and COGTA (Department of Co-operative Governance and Traditional Affairs).

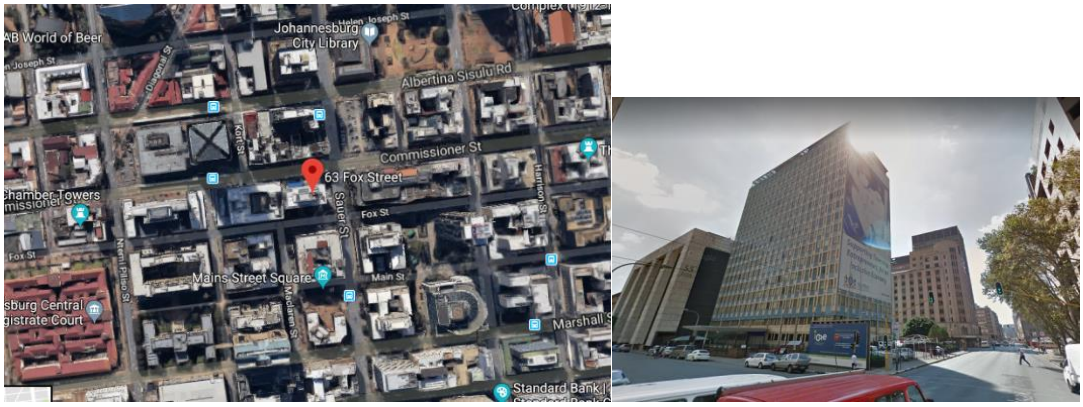

Figure 3: 63 Fox Street. Google map view (Google Maps, 2018)

3) Pritchard Street: This case study is a leased building situated at the corner of Pritchard and Joubert street. It is currently the new location for the Department of Safety and a 5 year lease agreement was signed. The Department of Safety is the sole tenant at the building.

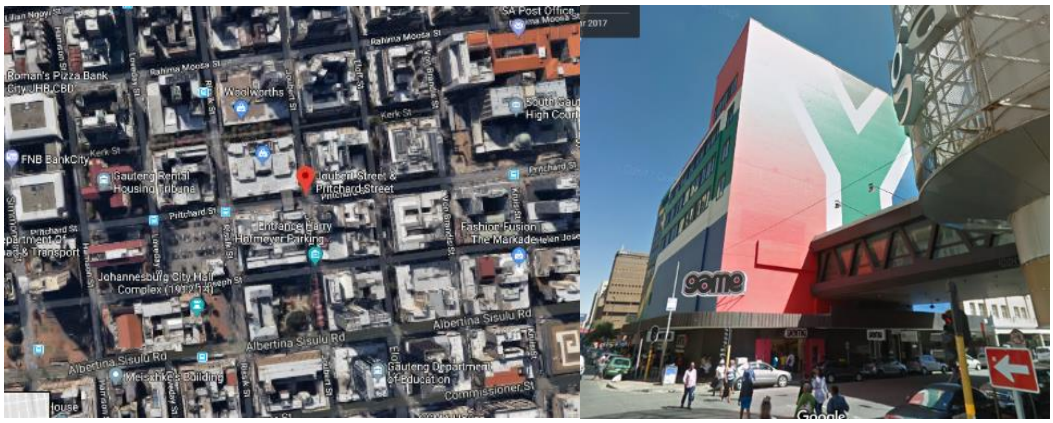

Figure 3: Corner of Pritchard and Joubert Streets. Google map view (Google Maps, 2018)

4) 6 Hollard: This is a leased building. The Department of Education needed to rent space. A lease agreement was signed. This building is situated opposite 78 Fox Street. Approximately 3-4 months installation time was required and the department moved in at the beginning of 2017.

Figure 1. 6 Hollard Street. Street view and Aerial View (The Heritage Portal, 2017)

Kopano: Environmental, economic and social concerns and solutions were clearly articulated during this interview. Affordability and optimising government departments spend were concerns raised. The respondent in Kopano Building felt very strongly that the PPP model is the optimum and feasible model for implementation. In leased buildings the department is funding the refurbishment through their rentals per month. According to the respondent in these type of instances the landlord is driving the refurbishment and maintenance projects with little or no inputs from the tenants. It emerged that that currently millions of rands are spent leasing other buildings (not owned by the government). This results in the government paying for fixing of the landlord's buildings. Another strong point the emerged was to forge a strong relationship between the well-being of occupants and their relationship with buildings. Improving the building to offer other amenities like accommodation could go a long way in reducing the transport costs. Another positive note that emerged from the discussion was that of the aspiration toward Green Star certification. The intention is to consider all buildings within the precinct project for Green Star South Africa minimum 4 Star rating. The respondent indicated that many green building initiatives are already intended for implementation and an assessment of the certification requirements could demonstrate that certification is considerably within reach. The rooftop solar green building technology is intended for widespread or total implementation across all buildings. The internal design team is aiming for 50% energy generation of the building requirements. The rooftop garden concept also has multiple benefits including supporting occupant well-being and social interactions and development

Corner House: The respondent claims the government recognizes and believes in the green building initiatives and aspects that will result in better sustainability of government buildings. The GDID is serious about this and has a green building directorate. The respondent's team has worked closely with the green building directorate to establish the existing state and look at solutions to improve the performance through green initiatives. The respondent indicates that they ensure that when mechanical systems are being replaced that they are replaced with energy efficient systems and this is the same for water fittings. Special attention is paid to source water efficient fittings where possible especially regarding low flush and dual flush wc's. Corner House project is one of the projects that implemented monitoring systems. At Corner House both water and electrical monitoring systems were installed to measure if the objectives have been achieved. Even the separation of waste was considered at The Corner House but was not possible to implement at the project. It is much easier to implement waste separation and bio digesters at schools and hospitals when compared to office buildings. Schools and hospitals are also making great progress regarding the implementation of water and energy monitoring systems. Roof top solar was implemented at Corner House project. The target is for 30% of building energy requirement to be delivered via the rooftop solar intervention. Social impacts were considered at the Corner House project through resting and waiting facilities and interacting areas but the respondent indicates that this will be significantly intensified at the Kopanong precinct project.

The Pritchard Street: The Pritchard Street case study was unique and fortunate that the existing building prior to being occupied by the government, was a dilapidated and unoccupied building. This meant that all new mechanical and electrical systems had to be fitted. The department

had an opportunity here to influence solutions selected and this resulted in energy efficient mechanical and electrical systems beings installed. New plumbing and water efficient fittings and fixtures were also installed. The installation of energy and water efficient solutions may not have been possible in a typical leased out building where these installations would be existing and in working order. At Pritchard Street too, like Corner House case study, efficient space planning was a key focus area. Unfortunately, At Pritchard Street too, like Corner House case study, the existing external fabric was not improved upon. This is a lease out building owned by an independent landlord and therefore not in the interest of the government to invest in improving the performance of the existing external façade.

6 Hollard: Like earlier interviews and discussions, here too it is reinforced that societies focus is on hospitals and schools. This is identified as the greatest need and the current public needs far outweigh the current financial and human resources available. The department is often met with the challenge of why it is not using its own building stock rather than renting other buildings. The respondent indicates that it is much more complex and a variety of aspects must be considered. It is attractive and easier to engage a landlord and pay a market related price and not concern oneself with maintenance except changing minor things like a light bulb when required. Regarding key areas for improvement that are noted; decreased utility bills was the priority. Installing of smart meters and monitoring consumption is taking place and is positive. Grey water and black water recycling should feature but this is currently only being explored in healthcare and education projects. Understandably, these initiatives are complex and require much consideration and testing. Like the case studies described earlier, here too these is no attention to improving the performance of the existing building fabric from an acoustic and thermal perspective.

CONCLUSION

South Africa has made significant strides in embracing the ideals of sustainable development in the construction industry. The neglected issue of how to forge compliance with the ideals of sustainable development in existing building stock has been brought to the fore. The main problem is currently ensuring that the ideals are immediately met even where the government is not the owner of the property. The greatest challenge appears to be dealing with the envelope of the building which is still functional but not necessarily enhancing sustainability, as the materials might lead to a heightened energy consumption and need constant refurbishment although due to their durability and initial cost might not immediately justifiably legitimize replacement. This challenge could be dealt with by entrenching long-term views and aspirations when private accommodation is sought.

The government appears to be leading the way in the replacement of mechanical, water reticulation and energy equipment which can only inspire the private sector generally if it is handled properly. On the whole the South African government has worked very hard in ensuring that the ideals of sustainability are understood by the civil officials. The provision of own accommodation and/or embracing Public Private Partnerships (PPPs) appears to be way the government could have more control on the type of facilities it uses to meet its environmental aspirations. The promulgation of directives dealing with the well-being of occupants appears to be forging a new culture in how property is going to be measured and inculcating a new paradigm in sustainability discourse. This approach could be instructive to

other jurisdictions that are aim to be exemplary in as far as government accommodation provision is concerned.

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EMOTIVE ARCHITECTURE – SENSORY DESIGN EVALUATION OF SCHOOLS

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Keywords: Post Occupancy Evaluation; Architecture; Human senses: sight, smell, touch, hearing, equilibrium, Intuition; Schools.

Abstract

Post Occupancy Evaluation (POE) is an established process for assessing the thermal performance of buildings already constructed and in use. It could be argued that POE tends to focus predominantly on assessing whether a combination of building fabric and the mechanical and passive systems meet design aspirations for minimising occupant or user energy use for heating and cooling, and maximising thermal comfort and indoor air quality. Yet, POE rarely assesses the sensory experiences of the building users and their perceptions of how well a space works for its intended function. It is also rare to find a POE approach that gives equal weight to the technical performance of buildings and the satisfaction of inhabitants and their aesthetic experience of the architecture (Tweed, 2017). POE for Architects needs to be a different approach that incorporates user sensory 'feelings' that are informed by sight, smell, hearing, touch, and taste. The first author of this paper is an Architect with 30+ years' experience, is award winning for his school design in Wales and works for Stride Treglown Architects in Cardiff. He is investigating the sensory experiences of buildings users in some of the schools that he has designed and that are in use. The data generated by this project will be used to enlighten his and their design of future school in Wales. Furthermore, this D.SBE project is timely since there are many new schools which are to be designed and constructed in Wales over the next ten years. Therefore, the Sensory POE approach developed during this work could enhance the services that Stride Treglown offers its clients, with a possible way in which clients can better understand their buildings in order that the users not only are more productive and happy, but also appreciate the architectural delight of a building and its spaces.

INTRODUCTION

The first author is an architect with significant experience in all types of buildings. Currently he is employed at Stride Treglown (2018) which is an established and well respected architectural practice with over 300 staff, and offices around the UK. The ethos of Stride Treglown is to provide the experience of 'delight' to building users and anybody who comes in any physical contact with their designs of both the building and the landscape. Stride Treglown are keen to develop a more meaningful Post Occupancy Evaluation (POE) process to gather information on their completed projects. Architects require a very different type of feedback to engineers (ibid). It is more important to architects to know how the occupant *feels* about the spaces they

have designed. This paper sets out the author's initial proposal for researching how internal environments are perceived, to establish a meaningful procedure for gathering feedback from clients after they have settled into their new building.

As part of their continuing need for feedback Stride Treglown (2018) has recently added a new section to their website known as Inhabitants, which is their approach to POE. Feedback from this form of POE is an opportunity to see how the intended design for their projects has worked, or not. It differs from the various established POE methodologies currently available in the UK, including Soft Landings from BSRIA (2018), the BUS Methodology by ARUP (available from Building Date Exchange, 2018). Similarly there is the building performance evaluation process developed by Innovate UK (Palmer, et al. 2016). Data collected in this way tends to be building performance related, making it a process more useful for the gaining knowledge of how the building fabric and services are performing. It is useful data as it demonstrates the fundamental purpose of a building, which is to provide shelter from the local climate. Tweed (2017) has noted that it is rare to find an approach that gives equal weight to the technical performance of buildings and the satisfaction of inhabitants and their aesthetic experience of the architecture. The first author's research will be developing a procedure to gather the aesthetic experience of architecture, with particular reference to the design of schools in the UK.

In view of the wide uses to which a community building such as a school has to provide, it is crucial for architectural designs to incorporate a range of measures to allow for the fullest range of user abilities and disabilities. Some users may have an enhanced level of sensory development. For example, visually impaired pupils develop a greater use of touch as well as a dependence on sound. People who are blind from birth are able to detect tactile information faster than people with normal vision (Goldreich, 2010). Hearing impaired pupils require higher quality of lighting and rely on their visual skills. A study published in the Journal of Neuroscience by Karns, et al. (2012) noted that people who are born deaf, use areas of the brain typically devoted to processing sound to process touch and vision. These findings are part of the growing research on neuroplasticity, the ability of human brains to change with experience. The first author has experience of inclusive design, resulting in an awareness where there is an advantage in designing for a range of disabilities, as it will enhance the perception and enjoyment of spaces in those without disabilities.

The benefits of multisensory design in schools has inspired the first author to consider incorporating sensory responsive devises in the buildings he has designed. These devises are deliberate interventions in the design of school which are not fully realised until the occupants make use of the buildings. Sometimes building users can sense a response without knowing how or why they feel better about the spaces they are using. The aim of this research is to establish a better understanding of how building users perceive spaces and to develop a vocabulary for architects to use when presenting design proposals to clients. It will become a value *added* procedure in future design reviews as well as a means of gathering post occupancy feedback for Stride Treglown.

Special Educational Needs covers a wide range of disabilities. Within that range there is Autism which has a wide spectrum of disabilities ranging from barely apparent disabilities to serious responses to the built environment. Autistism spectrum disorder is a group of disabilities that

affects communication, behaviour and social interaction and interests. It is more commonly known to be prevalent in boys Meng-Chuan Lai (2015) and this assumption can affect inclusiveness of female pupils who are better able to hide the symptoms, Sproston et al. (2017). Recent research carried out by University College London (UCL) 2017 has developed better ways to discover the symptoms in girls, who, they have found, are better at disguising their symptoms. UCL's research into autistic in females suggests a far greater cohort of people whose sensory perception is much more responsive than we might allow for in the design of buildings (ibid). The first author's research will investigate further into the neuroscience being researched by UCL and by Simon Baron Cohen (2013) who says there could be similar sensory responses relating to visual as well sound aesthetics particularly in adults.

CONTEXT TO LITERATURE

The first century Before Christ, the Roman architect Vitruvius Pollio identified three elements in architectural design: *firmitas, utilitas, and venustas (British Library, 2018)*. This was later translated in the seventeenth century by Wooton (1624) as the three fundamental elements in a well-designed building: firmness, commodity and delight. Delight is a perceived sense by occupants when using a building and so it is a primary concern for the architect. How people sense their environment is difficult to quantify. The first author's experience has discovered there are two further senses that designers might allow for: equilibrium and intuition.

- Equilibrium is all about balance; this can be with respect to physical balance (within the ear) but it can include visual balance, acoustic balance, thermal balance or even simply a balance of all.
- Intuition is possibly using all of our previous sensory experiences to interpolate a better understanding of the built environment.

The first author's experience in the design of schools suggests that all buildings should provide sensory clues both for the enjoyments and use by the disabled occupants and for the enhanced enjoyment of the spaces for able bodied persons who will also benefit from an increased use of their senses. Occupants perceive spaces through their primary sensory responses: sight, sound, touch, smell and taste. Mueller (2017). In his book 'Eyes of the skin' Pallasmaa (2006) the author statae that 'every experience of the environment is multisensory' and that it plays a central role as 'either a barrier or facilitator' of activity, participation and engagement.

Perception of space is a key element of architectural design. When developing the Canadian Model of Occupational Performance and Engagement the authors Gavin R, et al. 1997) identified three elements to spatial perception: Person, Occupation and Environment. For able bodied people these elements constantly influence each other both independently and simultaneously, but this interaction becomes less clear when the occupant is unable to draw on the full array of sensory responses normally available, Koutsoklenis, A (2011). Visually impaired occupants find the process of perceiving an accurate representation of the world very challenging. Their navigation through spaces often requires the assimilation of an array of sensory interactions to capture a meaningful awareness of the space around them. Clarke, et al, (2011) noted that this 'participatory relationship to a visually biased built environment

requires the use of tactile and audible sources of information to perceive awareness of motion as sensory clues within an environment to facilitate orientation about the built spaces'.

PROPOSED METHODOLOGY

Humans perceive their environment and the world in a variety ways but always through their senses. The intensity of these sensations is unique to each person and can vary according to personal moods at any particular time. This range of permutations of how humans might sense the environment makes it difficult to quantify an occupant's response.

As Tweed (2017) suggests 'feedback is essentially 'experiential'. To reinforce post occupancy feedback data the first author will implement an 'action research' approach for his Professional Doctorate in Sustainable Built Environment, by observing how occupants are responding to the designed spaces. The aim is to describe a "lived experience" of a phenomenon. Qualitative research is based on phenomenological methods as described in the research guidelines set out by Waters (2017). This approach will help the sample of building users to describe how they feel in the test environment, aiming to discover the relationship between the environment and physical and physiological experiences. It is basically an analysis of narrative data which is quite different from quantitative methods of research. Data will be collected through:

- Open-ended phenomenological interviews (Qualitative Research);
- Observatory behavioural experiments (Action Research).

Since architecture has primarily become a visual experience, participants will explore selected buildings twice: first through open eyes and then through closed or covered eyes. After each exploration building users will describe how they perceived the space's features, such as material, sound, heat, smell, dimension, as well as any other personal experiences they had, describing what aspects of the architectural design can be perceived other than visually. This will be a time consuming procedure and so sample sizes will need to be controlled. In the case of causal, comparative and experimental methods, Borg and Gall (1979) suggest a sample size of at least fifteen participants.

This practical approach to gathering data and information will be supported by a systematic review of current literature to provide a critical review the existing literature, and to provide supporting evidence from related papers, academic publications. The aim will be to highlight a gap in the practice for gathering post occupancy data, leading to a robust set of design principles that can be clearly understood and which can be conveyed to their professional designers. Omne of the outputs is anticipated to be a set of principles that will inform subsequent designs and offer some opportunity for corrective measures.

DISCUSSION

The architect and theorist Pallasmaa (2006) asks why and when there are five senses, sight has become so predominant in architectural design. Pallasmaa argues that the suppression of the other four sensory responses has led to the overall impoverishment of our built environment.

Pallasmaa queries why, when we spend over ninety percent of our lives inside buildings, humans understand very little about how the built environment affects our behaviour, thoughts, emotions, and well-being. He suggests that a better understanding of how the built environment influences us can help architects design buildings that are more enjoyable and sensorial. Indeed, it has been noted that Architecture is late in discovering the richness of neuroscientific research (ibid). Robinson (2006) maps out the opportunities available to architectural design through the engagement with cutting-edge neuroscience.

This engagement with the neurosciences will form the starting point for the first author's literature review. Pallasmaa (2006) concluded: 'it makes sense that architects and others in the built environment turn to science to help them understand how people interact, communicate, feel, learn, and heal'. Camargo (2018) has noted in her web site blog that 'some architects possess, through practice, study, and observation, a distinguishable instinct about how to create a good building', and, 'despite years of scholarship on the relationship between the built environment and our wellbeing, mental health is often treated as an afterthought to city planning and design', concluding that there is a 'lack of science in this sector' and 'there are no human-based metrics to help guide the design and construction of buildings. The only tools we currently have are the intuition of architects' ….. 'devoid of human data and knowledge'.

The first author's initial research appears to suggest that cognitive neuroscience might help to clarify human perception and response to physical spaces. As Camargo, A (2018) says: 'It can create a methodology of approaching building to enhance wellbeing, such as creating schools that are sensorialy orchestrated for learning and teaching'.

CONCLUSIONS

It is the first author's aim to increase awareness of how senses can be used to broaden the occupant's experience of the designed environment. In common language 'aesthetics' is often referring to how a building looks. But this omits the experience of acoustic aesthetics, thermal aesthetics, textural aesthetics and nasal aesthetics. Variation in sound, heat, air movement, light and smells the environment increases awareness of our environment. There is a risk that too much variation might over-activate the senses and cause discomfort. This research project is about developing a more holistic approach to sensory design so that our experience of designed spaces is much richer and more exciting. Stride Treglown will develop a robust procedure to seek meaningful feedback from their clients' perception of spaces, hopefully informing how they might fine-tune future design proposals.

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3D PRINTING IN CONSTRUCTION, HOW EFFICIENT CAN WE MAKE THE CONSTRUCTION PROCESS AND WHAT IMPACT DOES THIS HAVE ON ARCHITECTS/TECHNOLOGISTS?

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Abstract

3D printing was developing in 1995-2000 also known as Contour Crafting, which initially began as a ceramic extrusion and shaping method. These techniques could revolutionise the construction industry. Companies since then have been creating components of buildings using this process. This paper aims to address how the use of 3D Printing has been introduced into construction, and provide an insight into how efficient the latest technology can affect the construction process. This paper will also analyse the impact this has on architects at the forefront of design by being able to create complicated and intricate designs of which cannot be done with traditional construction and design methods. This new technology of 3D printing is an exciting prospect for all Architects and Contractors as it has the potential to become one of the leading technologies in the future due to its efficiency in producing innovative buildings and materials. This paper will use case studies from examples of where 3D printing in construction has been successful to cross examine and determine the efficiency and impacts of 3D printing on Architects/Technologists. The case studies will help provide different insights into the research of 3D printing in construction. The process of 3D printing has many potential advantages with faster construction periods, much lower labour costs as 3D printing has the ability to remove many physical human tasks in the construction process which shows the efficiency of 3D printing in construction. Most importantly, it can provide an increased complexity and accuracy to the design process (J.B. Gardiner, 2011), all of which will be examined throughout this paper. 3D printing in construction refers to various technologies that use 3D printing as a core method to fabricate buildings or construction components (J.B. Gardiner, 2011), with this there is a variety of methods used at a construction scale. Through looking into the various projects of 3D Printing, involving concrete geo-polymers and additive welding through the use of case studies, this paper aims to analyse the efficiency of 3D printing and its direct effect on construction methods, including its drawbacks.

INTRODUCTION

This paper aims to focus on the new and upcoming technology of 3D Printing (3DP) in the construction industry, as designers, architects and contractors explore the use of small scale 3D Printing for small components while others are thinking bigger. Dehue (2017) notes, 3DP is a process of making three dimensional solid objects from a digital file. This creation, in this case the object, is achieved by laying down successive layers of material until the object is created.

This process is commonly known in the industry as additive manufacturing and contour crafting (Dehue 2017). This research project looks to compare benefits and drawbacks of 3DP and aims to provide a new insight into this future technology. 3DP is becoming more and more prominent over the past few years in the construction industry, seeing entire buildings being printed instead of only certain materials. This paper will be structured as followed: firstly, analysis of case studies from two economically advanced countries (Office of the future, Dubai, 3D printed apartments, China and 3D printed bridge, Amsterdam) of which are at the forefront of the construction industry followed by two case studies which show incredible complexity of designs using 3DP (Vulcan Pavilion, China and MX3D Steel Bridge, Amsterdam). Secondly the paper will evaluate how efficient the 3DP process is when examining these cases. This will then be linked into the impact this has on current Architects and Architectural Technologists.

Overall, concluding the reason as to why there is an impact on designers is due to the 3DP technology becoming more incorporated into the construction industry. Through this it will be evaluated that contractor's and designers are opening their minds to more efficient and sustainable methods of construction; of which have the ability to produce more complex and difficult designs in an everchanging industry.

LITERATURE REVIEW

The beginning of 3DP identified by Head (2017), notes that Charles Hull 1984 was the pioneer in establishing the first method of this technique, known as steorelithography (SLA). Head (2017) notes the earliest use of 3DP, producing scaled models for architecture firms. Such models were beneficial tools for both selling and planning building projects. By the 2000s 3DP was at the forefront of the design industry, leading the way forward. Corroborating with such findings, Burger (2017) acknowledges that the "21st century has been the age of 3D," with 3D printing being the main and most attractive tool of companies such as Makerbot.

3DP became more widely available in 2010 (Crotty 2017), with many observing the accuracy of the design complexity that was produced. 3DP enables an architect to approach their project more like a sculpture. Futher to this, architectural models can send directly from CAD to be 3D printed due to the reliance on the same additive geometry as their starting point (Crotty 2017). Thus meaning, that an architectural model is essentially an exercise of "export-print" rather than a new deisgn project. Crotty (2017) claims one of the biggest advantages is that the average architecture firm, can make a big leap forward in the speed and quality in which they can iterate ideas from 3DP.

The efficiency of 3DP was early recognised, as it was a cheaper alternative to construct smaller models, compared to time-intensive, hand-made models that were the traditional way of construction (Head 2017). Behrokh Khoshnevis (University of Southern California), creater of Contour Crafting, poses a convincing argument signifying that the "only thing that is built by hand are buildings" in the contemporary era. Khoshnevis therefore questions whether 3DP can help to reduce costs and budgeting of construction in today's society (Burger 2017).

In line with the argument that 3DP will help to assist the construction industry, (Burger, 2017) distinguishes the five main advantages that comes with this innovative phenomenon:

1) Reduce supply costs
2) Global development
3) Greener construction
4) Improved project planning
5) Clarify client expectations

Burger (2017) recognises that 3DP will not solve all the problems within the construction industry, yet will reduce inefficiencies such as human error in planning. Balch (2017) considers the impact of 3D printing in construction, by acknowledging the Amsterdam steel bridge project, showing that the possibilities of 3DP are not limited. Further to this, the technology's productivity gains and safer working environments alongside the ability to build complex designs that are not feasible at this moment in time; make 3DP more than favourable.

Yet despite these advantages, the literature has identified drawbacks on the construction industry that companies should be "wary," as the increased automation and mechanization could be seen to be detrimental to the labour markets (Burger 2017). In addition to this, Balch (2017) identifies, 3DP in manufacturing is growing at a faster rate than in the construction industry due to the availability of materials, therefore significant progress is still to be made.

Moreau, a chief executive of the 3DP firm Sculpteo, identifies the problem of regulations with 3DP, which poses issues to many companies such as his, with the drawback of legislation being a hinderance to the advancement of 3DP (Balch 2017). Thasrathar (Autodsesk) contemplates that in the short-term, 3D printers of scale and sophistaction that are required are "too expensive for the average contractor." In addition to this, the skills required to operate the software programming of 3DP is a necessity and would require longer investment and time with engineers and architects.

Therefore, the literature has identified the evolution of 3DP, acknowledging the major benefits and drawbacks of incorporating this technique within the architect and construction industry. The literature has also recognised that there are limited papers on the efficieny of 3DP in construction. Consequently, the remainder of the paper, aims to draw on such benefits and drawbacks, yet in relation to the case studies of Dubai and China. In doing so, it will be evident that efficiency is the main outcome of 3DP and the drawbacks can be overcome with further investment and time into the technology.

RESEARCH REVIEW AND METHODOLOGY

This paper uses qualitative data via case studies as its research method and are a useful tool in conducting research into the public domain. Case studies have in the past as a research method have been criticised with lacking rigour and objectivity when compared to other social research methods such as questionnaires (Rowley, 2002). She also notes that case studies have often been viewed as a useful tool for the preliminary, exploratory stage of a research project as such with this papers research into 3DP.

Case study research is also good for contemporary topics, where a case study research uses a variety of evidence from different sources, such as documents, interviews and questionnaries, where this goes beyond the range of sources of evidence that would be available in other studies. (Yin, 1994) summarises, a case study is useful when answering "a how or why question". Thus, the correct method when answering this papers question on how efficient is the 3DP process in the construction.

A case study research method prominently uses data collection from various sources, (Rowley, 2002) provides an insight into three key principles which are to be observed when conducting the research:

1) Triangulation – using different sources in the case studies to corroborate the same fact or finding.
2) Case Study Database – a collection of all data and findings which helps strengthen the repeatability of the research while also increasing the transparency of the findings.
3) Chain of evidence – The paper should make clear sections on the case studies by using appropriate citation.

However, (McLeod, 2008) argues with the case studies efficiency in producing research results as the results cannot be generalised. As a case study only deals with one topic or event, the results that have been investigated are not representative of the wider body of "similar instances". There is also the issue of what is also stated via (McLeod, 2008) as "researcher bias" where the analysis of qualitative date depends on the interpretation of which the information is acquired. Thus, meaning there is a lot of scope for observer bias.

Nevertheless, this paper aims to analyse the various different sources and evidence of case studies of 3DP (Dubai, China, Netherlands). The case studies in Dubai (Office of the Future) and China (3D printed apartments) analyse the efficiency of the 3DP process in construction. The case studies in China (Vulcan Pavilion) and Netherlands (3D printed cycle bridge and MX3D Steel Bridge) discuss the complexities of design and the impact this has on architects. These will follow the protocals and principles as laid out by (Rowley, 2002) by looking in depth into how efficient the 3DP process is, in tail examining the impact this has on Architects and Technologists.

RESEARCH RESULTS

Case Study 1: Office of the Future, Dubai, UAE

Dubai is currently at the forefront of construction, with its industry booming. The United Arab Emirates (UAE) is a haven for architects and contractors, due to its wealth and ability to press forward in becoming one of the largest economies in the world. The UAE is known for its innovative and future thinking, thus leading on to Dubai's and, the world's first ever fully 3DP office building. Also known as 'The office of the Future'. The building was inaugurated in 2016 by His Highness Sheikh Mohammed bin Rashid al Maktoum, Vice President and Prime Minitster of the UAE and Ruler of Dubai. The initiative comes as part of Dubai's 3D Printing strategy, which focuses on the development of 3DP to improve people's lives. (Future Foundation, 2017) also notes that this strategy commits the UAE to print 25% of its buildings by 2030.

The office of the future is the first 3D-Printed building of its kind, where a 3D printer measuring 20 feet high, 120 feet long and 40 feet wide fabricated the offices. The building was constructed using the 3D Printer in sections and then transported to site for erection. The printing of the building took a total of 17 days and installed in just 2 days (Future Foundation, 2017). The subsequent work on building services, interiors and landscape took approximately 3 months. The labour involved in this process included one technician, seven people to install the components on site and 10 electricians and specialists to complete building services. This is a significant decrease in labour costs was cut by more than 50% compared to a conventional building of a similar size (Millsaps, 2017). The materials used in the 3DP process included a mixture of special reinforced concrete for walls and floors, glass fibre reinforced gypsum and fibre reinforced plastic. All of which were previously tested in the UK and China to ensure structural reliability and integrity in this new construction process.

Case Study 2: 3D Printed Apartments, China

China, like Dubai are known for taking risks within the construction industry and their technological advancements in general. Of which, Chinese company Winsun are at the front of 3DP in construction, where they were able to construct a five-storey apartment building and a 1,100square metre villa from a 3D printer.

(Starr, 2015) identifies the key aspects of the building and how it was constructed, using a 3D printer standing 6.6m high, 10m wide and 40m long. The building was fabricated within Winsun's factory and then assembled on site. The assembly was complete with steel reinforcements and insulation to comply with current building regulations. The efficieny of this construction was paramount, and a statement to the rest of the world, (Starr, 2015) notes the materials were extremely environmentally friendly using recycled construction waste, glass and tailings, around a base of quick drying cement with a special hardening agent. The 3DP process saved between 30-60% of construction, decreased production times by 70% and labour costs by 50% (Starr, 2015).

Winsun are a company who make statements to Architects and contractors within the construction industry by showing how efficient, environmentally friendly and how cost effective the 3D printing process is.

Case Study 3: Vulcan Pavilion, Beijing, China

China are also leading the way forward with the complexity of deisgn, not just through efficiency in construction. This has been shown by Yu Lei and Xu Feng of Beijing's Laboratory for Creative Design. The Pavilion designed represents the mushroom cloud that forms during a volcanic eruption. LCD (Laboratory for Creative Design) also say that Vulcan was inspired by silken, webbed filaments drawn from the research of cocoons. (Watkin, 2015) analyses the building and states the structure is comprised of 1,086 different 3DP constructive elements, making the structure nearly 3m tall. The pavilion itself took 30 days and 20 large scale 3D printers to complete. (Watkins, 2015) also notes that a further 12 days was required to assemble the pieces on site to form the pavilion. The pavilion is a statement to all architects and designers within the construction industry that the structure can be intricate and elegant while still being incredibly strong (Watkins, 2015). Architect (Lei, 2015) uses the Vulcan Pavilion to show other "modern architects" are able to achieve their ideal design quality from concept through to construction using digital design and fabrication methods. (Scott, 2015) also notes when analysing the fascinating structure that "before too long, brick and mortar buildings may be a thing of the past".

Case Study 4: 3D Printed Bridge, Amsterdam, Netherlands

The 3D printing phenomenon has also struck across Europe, in particular Netherlands who are leading the way forward with innovative design thinking to construct a 3D printed bridge, used mainly for cyclists and pedestrians to link two roads together over an 8m wide water ditch. BAM Infra, a construction company helped create this 3D printed bridge in the space of three months. (France-Presse, 2017) This is a significant decrease in construction period when comparing to bridges built in the traditional method. The bridge itself was constructed off site, in 800 layers of reinforced pre-stressed concrete. The bridge its self is not the most complicated of designs, yet shows absolute structural integrity as BAM Infra note the small cycle bridge is able to bear loads of up to two tonnes. (Salet, 2017) identifies one of the advantages of printing a bridge is that "much less concrete is needed than in the conventional technique". Marinus Schimmel, head of construction company BAM also notes that "we are looking into the future" adding "fewer resources were needed and there was significantly less waste" (France-Presse, 2017). (Block, 2017) agrees with the project noting that the unique deisgn uses far less concrete than a traditional poured concrete bridge, thus making it significantly more sustainable construction process.

It should also be distinguished that within this project, people were becoming "wary" of the 3D printing process as (Block, 2017) says workers are concerned about robots taking their jobs, yet (Salet, 2017) argues more labour will be made available as people need to build and maintain the 3D printers.

Case Study 5: MX3D Steel Bridge, Amsterdam, Netherlands

Architect Joris Laarman and start-up company MX3D are in the process of developing a 3D printed steel bridge, used for pedestrians, to cross over the Amsterdam Canal. Laarman acknowledges that this technology can produce "endless"

different structures (Hobson, 2015). This project slightly differs from the previous case studies researched as instead of using 3D printers,
MX3D developed 3D
Printing Robots. This was combined with a typical robot used in car assembly lines, combined with a welding machine and the 3D printing software. Thus allowing the robot to physically 3D print in metal. (Hobson, 2015) also notes that unlike traditional 3D printers, robots have the ability to produce much larger structures by moving across them as they print.

The steel bridge will span 8m, they had originally intended to print the bridge in situ, yet these became quite difficult over health and safety concerns, thus having to reconstruct the bridge in a workshop. Laarman's bridge will be printed in one piece, with the robots themselves printing a load bearing structure to support their own weight as they work.

The bridge its self may be small in size, but the structural integrity and complexity of design is what makes this one of a kind. In case study 4, a bridge was printed in the most common construction material (Concrete), yet this bridge signifies another step forward in 3D printing in construction by printing steel. (Hobson, 2015) also states that architects and designers are convinced that robots and 3D-printing techniques will be used more and more by the construction industry because of the design complexity. Laarman also states "this is just the beginning" when talking about 3D printing in construction (Hobson, 2015). The project is due to be finished in early 2018, with already a third of the bridge being printed.

DISCUSSION

How efficient is the 3D printing process in Construction?

3DP can be evaluated by using the previously discusses case studies, producing the argument how efficient is 3D printing in the construction process. Office of the Future, Dubai shows exactly what 3DP can do for the construction industry. The offices were printed within just 17 days and were then erected in just 2 days. This is a significant decrease in the construction period when compared to the traditional methods of construction. Thus, with a reduced construction time frame, the labour costs are dramatically decreased, reduced by 50% (Mislaps, 2017). This is also the case for the 3DP Apartments in China, where (Starr, 2017) notes that the construction period significantly decreased by 70%. Case study 3 also has a dramatic reduction in labour costs and construction periods. This being distinguished, the three structures are entirely different, one being a simple office design and the latter a five-storey apartment building to a complex pavilion. All of which were able to decrease their construction period and labour costs radically.

Cost is identified in the construction industry as one of the main contributing factors to successful projects, thus 3DP has a great effect on the construction process through the reduction in labour costs and the period a project is running. The 3DP process allows for shorter construction periods meaning less people are working on site and for a shorter time frame, thus labour workers are less at risk to health and safety issues. Therefore being able to save money, at a dramatic rate as shown in these cases and people becoming less at risk to health and safety issues, allowing the new technology to be extremely beneficial for contractors and designers in the industry.

It should also be distinguished that within this project, people were becoming "wary" of the 3D printing process as (Block, 2017) says workers are concerned about robots taking their jobs, yet (Salet, 2017) argues more labour will be made available as people need to build and maintain the 3DP technology.
A big talking point for the construction industry as noted by (Burger, 2017) is greener construction. All of these case studies have identified that 3DP has further benefits to the construction process as it is extremely sustainable, as the building is printed, no material is wasted. The 3D printed bridge in Amsterdam, is a perfect example as (France-Presse, 2017) acknowledges Marinus Schimmer, as he quotes "fewer resources were needed and there was significantly less waste". The apartment building in China also used recycled construction materials to produce the concrete geo-polymer forming the structure of the building. This sanctions the technology to be able to physically print in sustainable materials, as (France-Presse, 2017) notes producing less waste. Consequently, this helps show how sustainable and efficient the 3DP process is within the construction industry, again being significantly advantageous to contractors and designers in the industry.

What impact does 3D printing have on Architects and Architectural Technologists?

The impact of 3DP on Architects and Architectural Technologists is shown through the cross sectional analysis of the Vulcan Pavilion in China. This structure required 1,086 different 3D printed parts all of which are shown in a silken webbed format as described by (Watkin, 2015). This shows how a structure can be printed that is extremely fine-tuned, intricate and elegant. It could be argued that traditional construction method would be able to create this structure, yet this would require incredible craftsmanship and difficulty which would result in a longer construction period. The 3DP process is able to cut out this expensive process by producing structures of which Architects and Technologists deem to be elegant and complicated.

The complexity and difficulty in design is also shown through the MX3D Steel Bridge. As Joris Laarman quotes the technology can produce "endless complex structures" (Hobson, 2015). MX3D are able to physically 3DP a bridge out of steel in one print. In case study 4, they were able to 3D print a concrete bridge, one of the most common construction materials, yet MX3D's 3DP technology has allowed them to take that next step forward in the construction process by printing a more complex material of steel. Steel is known for its structural capabilities, but being able to print the material in a way that is highly favourable for Architects and Technologists means they can produce much more complex designs. Laarman states "this is just the beginning".

It can be noted that there are drawbacks on the 3DP process as the complexity of this steel bridge was "too" complicated to print in-situ (Hobson, 2015). This being said, a 3DP steel bridge is the very first of its kind, thus will challenge designers and Architects to overcome these problems. Of which was the case, as they moved the project into their factory to complete the printing process. Projects like the MX3D steel bridge and Vulcan Pavilion shows incredible complexity and precision engineering, but allows Architects to produce designs that are more free flowing, elegant structures. With this technology, designers are able to remove the aspect of physical human errors within the construction of the project, thus meaning structures are more likely to be constructed faster and much more precise than those that would require the human element of construction.

CONCLUSION

In Conclusion, this research paper has identified that 3D printing in the construction process is exceedingly efficient and that 3DP has a beneficial impact on all architects and technologists as they are able to produce more complex and intricate structures that would be difficult to produce using traditional construction methods. The 3DP has shown that within the construction industry the process can remove physical human errors, become a more sustainable construction method, dramatically reduce labour costs and construction periods. This paper has also analysed the drawbacks of the contemporary technology where printing materials are limited, being able to print on site can be difficult. However, this has also been argued that, printing off site can be more sustainable, safer and quicker within the construction industry. With this technology comes a new era of construction, of which will benefit architects, technologists and contractors in the construction industry, with more time and investment the 3D printing process will become a common construction method and used by all.

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General Track

TOWARDS A FRAMEWORK TO SUPPORT FLOOD RISK ADAPTATION MEASURES FOR VULNERABLE COMMUNITIES

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Keywords: Flood Insurance, Community Resilience, Flood Risk Management.

Abstract

The UK Government's strategy Making Space for Water (2005) heralded a change in approach towards flood risk management (FRM). Since then there have been major improvements in aspects of FRM, such as forecasting and the dissemination of information related to flood risk. Similarly, flood insurance, another facet of FRM, has changed. Flood Re, a scheme that laudably provides affordable flood risk insurance for low-income home-owners, excludes provision of insurance to those in the rental sector (private and social). Those in the rental sector have either little or no access to help and assistance if their home is flooded. In 201516, 4.5 million households were renting. A significant proportion of those households are found in vulnerable communities located in areas of high risk of flooding. This paper introduces new research to examine how tenure effects access to FRM and develop a framework that can be used by policy makers at national and local level to determine, and then support delivery of, FRM measures that are most appropriate to a community. The solution driven nature of this research has led to the adoption of pragmatism as the research paradigm and is likely to follow a multi-method/mixed method approach. The outcome of this research could help organisations and agencies responsible for provision of elements of FRM ensure fairer access to insurance and greater opportunity for involvement with FRM at local level. Building greater community resilience and hence greater sustainability.

INTRODUCTION

The scale and frequency of climatic events have increased in recent years and are likely to continue on an upwards trajectory for many years to come (International Panel on Climate Change, 2007; Sayers *et al.*, 2015; Vanneuville *et al.,* 2016) As a consequence, the UK has experienced increasingly damaging flooding, which has led to loss of life, as well as severe structural damage (property and infrastructure) and disruption to society (Pitt, 2008). The economic impact of the flooding in 2007, was estimated at £3.5Bn, while the financial cost of the intangible effects of the flooding, partly characterised as impacts on mental health and days of schooling lost, was estimated to be £250M (Environment Agency, 2010). The latter figure is likely to be lower than the final cost because of delayed manifestation of some effects and the inability to make clear causal links between flooding and some health conditions (Mason *et al.,*

2010; Azuma *et al.*, 2014). Socially, economically, as well as environmentally, society cannot sustain the increasing burden associated with flooding.

Until 2016, the UK's response to flooding, particularly domestic property, was governed by a Statement of Principles - an agreement between the UK Government and the Association of British Insurers whereby the UK Government agreed to underwrite losses. The Statement of Principles was replaced by Flood Re in 2016. Although Flood Re provides affordable flood risk insurance aimed at low-income households, currently it excludes provision of insurance to those in the rental sector (private and social). It is anticipated that the size of the rental sector is likely to increase in the coming years (Department of Communities and Local Government, 2017). Hence difficulty in accessing affordable flood risk insurance and the potential lack of feeling of placement due to churn (frequency of moving home), is likely to leave those in private rented housing, and to some degree those in social rented housing, exposed to the impacts of flooding. On top of that is the fact that of those people living in rented accommodation, a large proportion are likely to be vulnerable. Some of the factors identified by sociological researchers examining social vulnerability include; socioeconomic status; gender; race and ethnicity; age; rural/urban; type of residential property; renters; occupation; family structure; education; medical services and socially dependent needs populations (Cutter *et al.,* 2003; Willis & Fitton, 2016). Although admittedly not everyone categorised vulnerable is likely to be renting, greater exposure of the vulnerable to the impacts of flooding is likely to increase the burden on local communities, as well as society as a whole. Although there have been moves in the UK to build greater levels of community resilience, partly through involving individuals and communities in decision making, the most vulnerable in those communities, including those in rented accommodation, are likely to remain marginalised. This research will contribute to the body of knowledge a new decision support framework that would be inclusive. That would mean that all elements of society, some of which are not currently given fair access to flood adaptation measures, can take part in the decision process and help shape adaptations that affect them.

BACKGROUND

The Pitt Review (2008) led to significant changes in governance associated with the formulation and subsequent implementation of UK flood policy and reinforced the change in emphasis in UK flood policy, away from structural defences (holding back the water) to flood risk management (FRM) (learning to live with water) (Nye *et al.,* 2011). In the 2007 Comprehensive Spending Review it was intended to 'positively target deprived households in the flood defence planning and asset capitalisation process'(Nye *et al.,* 2011 p.290). That focus on deprived households is lauded but until recently the issues of social and environmental injustice appear to have been largely ignored. UK FRM Policy has focussed on the technical aspects of FRM, such as improved forecasting, the dissemination of information related to flood risk and building sociotechnical resilience. Social injustices related to UK FRM have come to the fore again prompted partly by the recent introduction of the flood related reinsurance scheme, called

Flood Re. Although a high level aim of Flood Re is to promote affordable flood insurance for those who are least able to pay (UK Government, 2015 p.3), there remains concern among academics and others in Industry that the benefits of the scheme will not reach some sectors of society (Penning-Rowsell & Pardoe, 2015; Penning-Rowsell, 2015; Surminski & Eldridge, 2015; Surminski, 2017) exposing people to social injustices. Sayers *et al* (2017) go further and suggest that there is now need to 'embed positive discrimination in FRM investment decisions to target support to the most vulnerable communities'. The concepts of vulnerability and resilience, as well as social justice, are crucial to an understanding of the sociotechnical aspects of FRM.

Vulnerability

Although loss of entitlement and exposure to risk can be used successfully to define the vulnerability of a system in the face of a relatively simple hazard event, it is suggested that together they lack the fidelity to define the vulnerability of systems to natural events resulting from climate change (Brown, Ecclestone & Emmel, 2017). Instead a wider systems approach to conceptualising vulnerability is more useful. This allows researchers to consider the social, economic and institutional factors that influence levels of vulnerability within a community and, which either promote or constrain options for adaptation (Kelly & Adger, 2000). Although taking a systems approach to vulnerability would certainly result in a comprehensive assessment, to get the most out of an assessment, it is essential that the context and purpose of an assessment is also made clear from the onset (Kelly & Adger, 2000; Füssel, 2007). Reviews of vulnerability assessments note a lack of integration between academic analyses of vulnerability and governmental and non-governmental policy uses (Mustafa *et al.*, 2011). This lack of integration between research outputs and policy enactment is part of the motivation to develop a framework that incorporates a range of vulnerability indicators previously shown to define and influence vulnerability, so that policy makers can develop and adjust responses to natural events.

Resilience

Although use of the concept of resilience outside of its normal engineering base is relatively new (Twigger-Ross *et al.*, 2014), it is often linked with the concept of vulnerability. It is now a crucial element of integrated FRM. A benefit of the concept of resilience is that it has positive connotations rather than negative ones, which are usually associated with the concept of vulnerability (loss of entitlement and exposure to hazard). Furthermore, in simplistic terms vulnerability can be regarded as the pre-event assessment of a system, whereas resilience is the post-event ability to recover and bounce back from an event. Despite the simplicity of those views, some researchers opine that the relationship between resilience and vulnerability is certainly not clearly defined (Cutter *et al.,* 2003; Cutter *et al.*, 2014). While others have even suggested that there is a 'danger of resilience becoming a vacuous buzzword' because of its 'overuse and ambiguity' (Rose, 2007 p.384). Others are unequivocal suggesting that emphasis on resilience and the lessening of attention on vulnerability is problematic because it removes

a power related connotation of vulnerability (Cannon & Muller-Mahn, 2010) and ignores the behaviours of actors with differing levels of power. Cannon & Muller-Mahn go further and suggest that 'vulnerability is therefore a more valid concept, since its construction is valid under existing and new conditions and is rooted in economic and political process that can be analysed alongside those of climate and ecosystems' (2010 p.623). They conclude that 'a resilience approach depoliticises the causal processes of putting people at risk' that 'leaves the poor and vulnerable behind' (2010 p.633). That criticism is understandable if one considers resilience from a single viewpoint, discounting the complexities of both the risk and potential solutions.

Social Justice

The issue of underlying vulnerabilities and inequalities in terms of race, gender, and poverty were revealed starkly by Hurricane Katrina in 2005 (Douglas *et al.*, 2012). Consequently, flooding and its impact in terms of preparation, response and recovery are now also considered by some researchers as an issue of environmental justice (Walker & Burningham, 2011) and social justice (Johnson, et al., 2007). The concept of social justice follows the notion of 'a society made up of interdependent parts, with an institutional structure that affects the prospects of each individual member, and that is capable of deliberate reform by an agency such as the state in the name of fairness' (Miller, 1999, p.4). In simple terms, social justice can be distilled into a fair and just relation between the individual and society. Hence a key tenet of the proposed research is that despite the high-level intent of Flood Re, accessing some FRM, namely insurance and adaptation measures, is not available fairly in the UK. Another feature of social justice is the disproportionate level of representation of the poor in society in decision making (Preston *et al.*, 2014). Crucially social justice and inequality could be diminished by greater involvement of the poor in decision making, although involvement seems low because the decision making processes are restrictive (Preston *et al.*, 2014). Despite increased opportunity for involvement in decision making at the local level, it is likely that national policy makers will still have undue influence over local action. In their assessment of the interplay between governance structures at local and national level in Norway, Næss (Naess *et al.*, 2005) shows that despite the local councils being an appropriate institutional level for adapting to new flood risk and having high legitimacy among those at risk, they are often stymied by agencies of central government seeking to shift and spread financial risks and consequently heightening vulnerability. It is highly likely that phenomenon pervades the UK too.

In spatial terms, the poorest are more likely to live in areas of high risk of flooding for all types of flooding and often in types of housing that cannot easily be modified to build in either resistance or resilience (Preston *et al.*, 2014). When spatial figures are disaggregated between fluvial and coastal flooding the greatest influence on the increased exposure to risk for the most deprived comes from coastal flooding (Walker *et al.*, 2006). There is strong and clear evidence that the most deprived people are 122% more likely to be living in the sea flood zone than the least deprived (Walker *et al.*, 2006). Further regional analysis also showed that the coastal flood risk population in the most deprived groups is concentrated in London and Yorkshire and Humberside (Walker *et al.*, 2006). In 2010, Whittle *et al* reported-on lessons learned from the Hull flooding in June 2007. Although the council tenants affected were much better protected

by regulations than those in the private rental sector they were still vulnerable in several ways. Crucially they had no say over the repairs to restore the property - what property level protection measures were installed – and had no control over the duration of the restoration. Where private renters found alternative accommodation and they

could afford it, it was often a significant distance from their 'home', resulting in dislocation from work and established social networks. If they had children, there was added pressure to maintain continuity of education. At this stage, it is important to note that in 2015-16, 4.5 million households were renting in the private sector, which represents 20% of all households in England. Throughout the 1980s and 1990s, the proportion of private renters was steady at around 10% (Department of Communities and Local Government, 2017). Hence vulnerability is likely to be exacerbated by combining exposure due to tenure with other socio-economic characteristics of vulnerability, heightening potential for social injustice (Kelly & Adger, 2000).

Determining Levels of Vulnerability and Shaping Responses

Thrush *et al* (2005) published their technical report entitled Flood Warning for Vulnerable Groups: Measuring & Mapping Vulnerability and attempted to measure and map vulnerability to environmental hazards, considered the potential for mapping vulnerability to flood risk in the UK and illustrated the importance of selecting an appropriate area or unit of analysis (Thrush *et al.,* 2005). This work complemented earlier reports that provided overviews of the issues of social inequality in natural hazard research and the results of qualitative enquiry into vulnerability about flood warning awareness and response and vulnerability during a flood event (Eves, 2004). These were examples of the line of enquiry 'en vogue', which was reflected in the MSW Strategy, although the MSW Strategy surprisingly put emphasis on the effect of flooding on rural communities (DEFRA, 2005). In the UK, much of the other work in the field of vulnerability to the impact of flooding and shaping responses originated from the Flood Hazard Research Centre (FHRC) at Middlesex University. In 2002, the FHRC developed the Social Flood Vulnerability Index (SFVI), which was incorporated in the Environment Agency's (EA) Modelling Decision Support Framework (MDSF) (Thrush *et al.,* 2005). With work completed by Walker and Burningham addressing environmental inequalities to flood risk (2006), again undertaken on behalf of the EA, disappointingly this represents a significant effort that appears to have come to nought. Once again, since 2008, emphasis appears to have been put on development of flood warning systems highlighting exposure to risk and building community resilience, neglecting refinement of measures of vulnerability and the development of indices that could support decisions about where best to focus non-structural flood risk management interventions to enhance resilience locally. Despite this earlier work, during recent research Sayers et al reported that policy makers all expressed the wish to address the needs of vulnerable communities in the future but no systematic assessment of the changing risks in the most vulnerable areas was offered (Sayers *et al.*, 2017). The aim of the work by Sayers et al was to determine whether the relationship between social vulnerability and exposure to flood risk across different communities is a prerequisite to delivering a socially just approach to prioritising flood risk management efforts within national policy and funding structures (Sayers *et al.*, 2017). This assessment highlights significant variation in flood disadvantage across the

UK. For example, ten local authorities account for fifty percent of the most vulnerable people that live in flood prone areas according to the Neighbourhood Flood Vulnerability Index (NFVI), a metric based around ONS census data, introduced by Sayers et al (2017). In turn, coastal areas, declining urban cities and dispersed rural communities are also highlighted as representing
the greatest concentrations of disadvantage. This report appears as a very timely 'refresh' of the earlier strands of work.

AIM OF THIS RESEARCH

The aim of this research is to develop a framework that can be used together by policy makers and local communities to determine, and then support delivery of, flood risk adaptation measures that are most appropriate to a community.

FOUNDATION OF RESEARCH

A foundation of this research is Lupton's and Power's (Lupton & Power, 2002) description of the inter-linked effects of area concentration of disadvantage, which is likely to affect opportunity to build community resilience. Figure one is adapted from that work and incorporates additional factors identified during the initial literature review that are often used as the basis for categorising people as vulnerable but have hitherto not been given sufficient weight in determining willingness to adapt to risks at both individual and community levels. One example is that of spatial detachment of a community from policy leads.

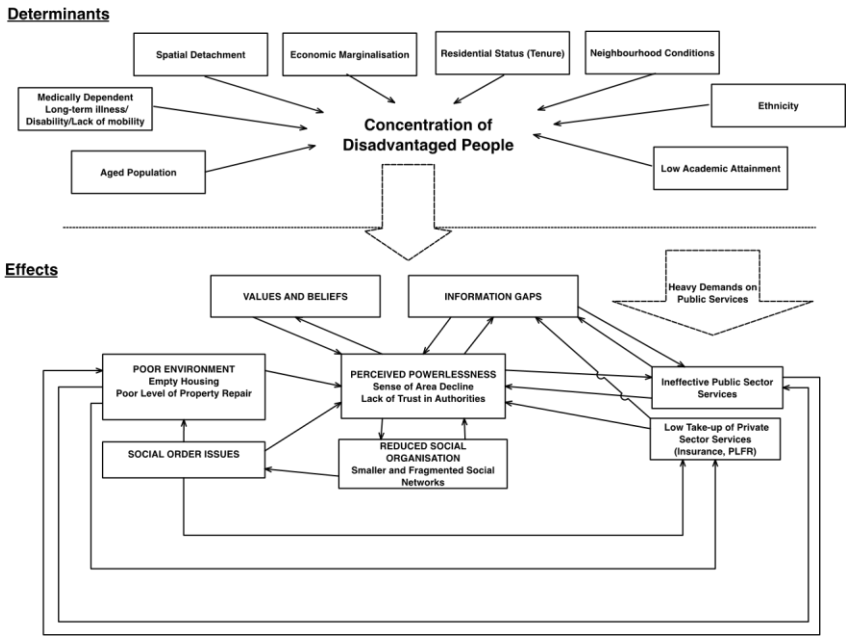

Figure 1 – Inter-linked and Compounding Effects of Area Disadvantage

Lupton and Power (2002) also question whether 'standard' deprivation indicators are accurate predictors of how a community will react to adversity. There is risk that the indicators neither reflect the uniqueness of a built environment nor account for specific personal circumstances. Moreover, it is likely that the lexicons of indices, coupled with the complexity and volume of associated data and information, may be overwhelming. Consequently, it is felt that these 'standard' indices are unsuitable bases for consensual based decision-making for all in a community. On the grounds that the proportion of the UK population living in rented accommodation is growing, of which a significant element is likely to vulnerable, there is need to understand how tenure effects accessing FRM measures for those people living in areas at high risk of flooding and develop a framework for assessing risk such it can be used to shape policy, and ultimately delivery of FRM, at both local and national levels.

CONCLUSION

Recent tragic events have brought the vulnerability of individuals and whole sections of society, the concept of social justice and the topic of building resilient communities again into strong relief. Although Central Government has continued to build structural flood defences that protect whole communities from flooding, it has also focused attention on sociotechnical solutions to FRM, such as improving flood warning systems and easing access to property based flood insurance. Despite those changes some parts of society remain significantly exposed to the impacts of flooding. In particular, where the rental market is burgeoning there is need to understand the effect of tenure on accessing FRM measures and where necessary developing a mechanism for influencing policy and subsequent delivery of FRM in vulnerable sections of society.

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PERCEPTIONS OF TELETUBBYLAND: PUBLIC OPINIONS OF SUDS DEVICES INSTALLED AT ECO-DESIGNED MOTORWAY SERVICE AREAS

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Keywords: BREEAM, Drainage, Runoff, and Natural landscapes.

Abstract

Sustainable buildings, sustainable businesses and sustainable behaviours are befitting of modern society. Combining these ideals has been realised in the UK's greenest motorway service areas (in Gloucestershire) where public perceptions towards the installation of sustainable drainage devices has been studied. Whilst the planning of sustainable drainage systems has gathered momentum (since the late 1990s), it is readily acknowledged that there is a deficit of community awareness and knowledge of the purpose, function and wider potential benefits derived from devices used to manage and minimise surface water. Until there is a comprehensive shift away from the traditional approach of underground piped drainage, blue-green infrastructure will remain a relatively unknown entity for the populace and a concomitant shortfall in demand will be encountered. Therefore, public opinions of the motorway service area eco-designed amenity buildings (green roofs) and their surrounding landscapes (swales and ponds) were sought through questionnaire surveys (n = 86) completed by visitors to both the southbound and northbound M5 Gloucester motorway service areas. Results reveal the public share unanimous support for the eco-design sustainable buildings (designed to achieve BREEAM Excellent), and an overwhelming enthusiasm for the aesthetic landscaping of the sites. However, it was clearly evident that visitors were not forming a link between the appearance of the motorway service area features and their associated role in contributing to the sustainable surface water management of the sites, despite the architect's design intention for the landscape to be readily understood. It is concluded that a shift from 'grey infrastructure' will require the involvement of all stakeholders and changing public perceptions of 'blue-green infrastructure' will remain an obstacle until awareness of its value is far-reaching and celebrated beyond the confinements of architectural drawings and planning applications.

INTRODUCTION

The impact of urban development on a catchment (by reducing its permeability and increasing surface water runoff) reduces opportunities for water to be managed naturally on site and can lead to localised flooding, the affects of which are exacerbated when traditional piped drainage systems are unable to cope with heavy rainfall. Recent increases in instances of severe weather events, such as the wettest January (2014) in the UK since records began in 1910 (Met. Office, 2014), flooding has been identified as the most dangerous impact of climate change for the UK, hitting harder and faster than expected (Carrington, 2014).

Effective surface water management within the UK has become an important topic in recent years as the current shortfall in development land for housing has led to a marked increase in the number of areas at risk of flooding being developed and considered for development (Sayers, 2012). Sustainable drainage systems are becoming essential in managing effective stormwater infiltration (Thompson, 2014). The need to manage the capacity of surrounding land in dealing with unusual weather patterns and reducing the pressure on basic stormwater infrastructure is essential in providing a healthy, functioning natural environment to sustain economic growth, prospering communities, personal well-being and reflect the critical value of nature (The EU Sustainable Development Strategy, 2006; UK Climate Change Act, 2008; Natural England, 2009).

Traditional underground pipe infrastructure is no longer seen as a 'silver bullet' for dealing with flood issues and today it is recognised as something that must be integrated within a broader portfolio of non-structural and policy responses to help deliver 'multiple outcomes' (for ecosystems, the economy and society), while promoting resilience to changing and less predictable weather patterns (Sayers, 2012; Cahill, 2012). Linking non-structural drainage systems with future development and regeneration can deliver greener and more pleasant urban areas (Rossmiller, 2014), with trees and vegetation combining to define the scale of space, making large, unfriendly spaces smaller in parts and more conductive to a wider range of human activities (Ashley *et al.,* 2012).

The concept of naturally-inspired flood resilience has begun to be incorporated into sustainable design across a range of industries, including the relatively new concept of the Motorway Services Area (MSA), which is a direct response to the need to provide rest and refreshment to users of the expanding motorway network (Pegasus, 2010). There has been a recent shift in the archetype of contemporary MSAs in the UK, towards sustainably-driven businesses, operating in eco-designed buildings that give attention to sustainable drainage (Charlesworth and Booth, 2016).

The M42 Hopwood Motorway Service Area in Worcestershire (completed in 1999) was the first MSA to incorporate SuDS. It utilises five principal SuDS components, with the aim of providing an affordable system, providing an attractive setting and added amenity (Robert Bray Associates, 2016). The system consists of filter trenches, a filter strip, swale, pond and wetland, forming two distinct management trains. Areas considered to pose a pollution risk to the environment have used the SuDS management train to ensure good water quality and deal with possible spillage events, with the HGV park, fuel filling area, coach park and service yard having an extended management train as they potentially pose a serious pollution risk (Dickie *et al.,* 2010). In general, water quality improves during passage through the more extended HGV and coach park SuDS, emphasising the importance of implementing SuDS units in management trains rather than in isolation (Heal *et al.,* 2008).

Following the continuing success of 'sympathetically landscaped' Tebay Services (2016) on the Westmorland stretch of the M6 motorway in Cumbria, in 2010, Stroud District Council approved a detailed planning application for a new MSA to be known as Gloucestershire Gateway Services, located between junctions 11A and 12 of the M5 Motorway (Pegasus, 2016).

The MSAs incorporate an extensive array of sustainable drainage processes within a carefully monitored management train, with features including green roofs, swales, bio-retention areas and filtration strips ultimately discharging to a pond and wetland area (Water Active, 2015). The site was designed to provide improved landscape infrastructure, permeability, biodiversity and habitat creation, reducing flood risk (BWB Consulting, 2016), having been designed for storm events in exceedance of 100-years, plus 30% climate change events.

The Gloucestershire Gateway Services set a new standard for MSAs and are recognised nationally as a model for future MSA development (Design Review Panel, 2013). This study explores public perceptions towards the sustainable drainage devices that have been incorporated into the eco-design of the amenity buildings and their surrounding landscapes at the southbound and northbound M5 Gloucestershire Gateway Services.

BACKGROUND

In England and Wales, the Flood and Water Management Act 2010 requires new developments and refurbishments to have drainage plans for surface runoff approved by the SuDS Approval Board (SAB) where the construction work would have drainage implications. The SAB is responsible for adopting and maintaining new SuDS that serve more than one property and have been constructed as approved and function as designed (Defra, 2011). A proposed drainage system in England or Wales will not comply with these National Standards unless it is designed so that surface runoff is managed at its source where it is reasonably practicable to do so, with the Sustainable Drainage (Approval and Adoption) (England) Order 2012 defining exemptions to the requirement for approval. Furthermore, public space must also be used and integrated with the drainage system, where it serves more than one property, and the SuDS design must be cost-effective to operate and maintain over the design life of the development, in order to reduce the risk of the drainage system not functioning. The design of the drainage system will account for the likely impacts of climate change and changes in impermeable area over the design life of the development (Defra, 2011).

Sustainable Drainage Systems (SuDS) are technically regarded as a sequence of water management practices, control structures and strategies to drain surface water in a manner resilient to changes in climate, whilst minimising pollution and managing the entry of pollutants that could affect the quality of local water bodies (Susdrain, 2015). “Blue-Green” systems combine and protect the hydrological and ecological values of the urban landscape, while providing resilient and adaptive “hard” and “soft” measures to deal with flood events (University of Nottingham, 2015). “Soft” SuDS are naturally-inspired landscaped measures that manage surface water typically above ground in a more sustainable fashion than traditional techniques. They often include trees and tree pits, swales, basins (dry, wet and infiltration), rain gardens and ponds. “Hard” SuDS are of an engineered nature and include geocellular storage, proprietory products, separators, hydraulic controls and kerbside drainage. Soft SuDS can, however, create multiple benefits, including biodiversity, and are more flexible and adaptable to climate change (Ashley *et al.,* 2012). A feature of retrofitting soft SuDS specifically is the introduction of more vegetation and trees into the urban landscape. This is a component of green infrastructure, helping to break down the harder appearance of constructed surfaces or unused green space and create a more pleasant vista (Balmforth *et al*., 2006).

The typical design of any SuDS system follows a step–wise hierarchy of various measures, commonly known as the 'Surface Water Management Train', which store and convey stormwater at different scales: (i) Prevention (e.g. land use planning); (ii) Source control (e.g. green roofs, rainwater harvesting, permeable paving); (iii) Site control (e.g. vegetation or gravel filtration); and (iv) Regional control (e.g. retention ponds, wetlands) (Woods–Ballard *et al.*, 2007, 2015). At the heart of SuDS is the "SuDS square", which introduces the notion that to be successful, SuDS design should balance the desire to control water quantity, improve water quality, provide public amenity and encourage localised biodiversity benefits. Management of surface water on a local level, mimicking natural processes, provides an essential method of reducing the extent of pollution and contributing compliance with the EU Water Framework Directive by controlling both diffuse and point source pollution of surface water (WFD, 2000).

Public perceptions of sustainable drainage is an important indicator of the level of knowledge about these types of system; however, perceptions may not be easy to gauge, especially when the multiple benefits of SuDS components are often concealed as a result of their integration into a landscape or by being designed in a natural way (Sayers, 2012; Blackburn, 2015). All new and innovative drainage technologies applied in either residential or commercial developments, besides being technically and economically viable, must be designed to be accepted by the public. Poor public perception of SuDS may be a deterrent for developers in using them at new sites (Susdrain, 2015a). Further, people are scantily informed about behaviours required to ensure continued functioning and the development of potential benefits from established devices. This will tend again to feed back to reduced functioning, worsened aesthetics, and further negative preferences (Everett *et al.,* 2015).

Implementing a shift away from hard "grey" infrastructure requires the involvement of all stakeholders, including local publics who will be affected, in developing new practices and behaviours to ensure functionality and sustainability (Everett *et al.,* 2016). Public perceptions of SuDS are likely to be linked to several factors, including scheme performance, biodiversity issues, education strategies, aesthetics, perceived health and safety risks, water quality and respondent socio-economic status. Safety has already been proven to be one of the main concerns regarding SUDS application, for both developers and the public (Susdrain, 2015a).

CASE STUDY

A partnership between Gloucestershire Gateway Trust and Westmorland Ltd. has facilitated the delivery of unique and visionary designed (BREEAM excellent) MSAs. Gloucester MSAs are unlike traditional services and appear almost seamless with their surroundings (Pegasus Planning Group, 2010). Costing £40million to construct (by Buckingham Group Contracting Ltd.), the buildings on each side of the motorway display similar designs, layout and floor space, with a main facilities building (~3,300 m^2), LGV drivers building (~30 m^2) and a petrol filling station (~230 m^2). The main facilities buildings are timber framed with lattice roof structures (~9m high) convened between solid dry–stone walls made of locally–sourced buff–coloured Cotswold limestone. The buildings are draped in a blanket of soil and turf to create bespoke green roofs supporting native grass covers, which contribute to the water management and biodiversity of the sites. Water conservation inside and outside the buildings incorporates

rainwater harvesting, low flow sanitary appliances, which include dual flush toilets and aerated flow restricted taps, plus leak detection and control (using smart metering), and low water landscaping that reduces the quantity and improves the quality of site runoff (Figure 1) (Booth and McLaughlin, 2017).

Figure 1: Images of the M5 Gloucester motorway service areas.

Drainage of the MSAs follows the SuDS management train and has been designed for storm events in exceedance of 100–years, plus 30% climate change events. Besides the source control measures already mentioned (e.g. green roofs and rainwater harvesting), a suite of devices have been incorporated into the landscape of the MSAs. The parking bays of the car parks (with kerb drains) and pedestrian walkways have permeable paving, which allow surface waters to percolate between the blocks to infiltrate and be stored in the stone beneath. The LGV parking and access roads are drained by shedding the flow to filter strips, before entering stone filled treatment trenches. A series of roadside swales and trenches (both wet and dry) provide an infiltration and conveyance network across the sites. These are joined by underground piped (various diameters) inlets/outlets, fitted with silt traps and flow control chambers. Excess waters eventually enter a series of ponds (permanent volume of 154.4m^3; maximum attenuation volume 1004.7m^3) and wetlands (permanent volume of 96.5m^3; maximum attenuation volume 556.4m^3) at the end of the MSA sites. As well as bestowing a visually attractive landscape, the sequence of site control devices improves the quality and runoff characteristics, which also contributes to the biodiversity and management of the MSAs (Booth and McLaughlin, 2017).

RESEARCH DESIGN AND METHODOLOGY

Data Collection

A questionnaire was chosen as an instrument for data collection because of the desire to consult as large and diverse a sample of MSA visitors as possible. It was designed to rapidly gauge individuals' perceptions, including their level of appreciation and understanding of the surrounding environment, without delaying them on their journeys or disrupting their experience of using the MSAs. For this reason, other methods were deemed to be impractical. The instrument was developed through an iterative process of literature reviews and consulting experts to refine the measurement items, before piloting with industry and academic

professionals. Feedback from the pilot exercise was used to amend and address possible issues before the final version of the questionnaire was distributed.

The main purpose of the questionnaire was to solicit public knowledge about 'blue-green' systems and their intended use and benefits, using the MSA as an exemplar case study because of its distinct eco-credentials, including extensive SuDS landscaping sympathetic to the local rural surroundings. Data about individual views on the environment, climate change and extreme weather events was also collected, together with a range of questions to determine the demographics of the participants. A five-point Likert-type measurement scale (from strongly disagree (1) to strongly agree (5) responses) was adopted to gauge respondent ratings of statements. These were funnelled into a narrow frame to ensure they were specific, measurable, attainable, relevant and time-based. A small number of open-ended questions (dual approach) were also included to elicit rich qualitative data, alongside the quantitative approach.

Ethical approval was sought before the final questionnaire was shared. Approval meant all participants were informed in a participant information cover letter that their involvement was entirely voluntary and their decision to complete and return their completed questionnaire was their consent to take part in the study. As their responses would be anonymous, participants were also informed that there would be no opportunity to withdraw once the questionnaire had been returned.

Data Analysis

Data was entered into SPSS (version 20) before analysis and descriptive statistical information derived. These are detailed and portrayed in the sections beneath.

RESULTS

The findings of the data analyses are presented beneath, under four main sections: (i) background information about the participants; (ii) their opinions of the environment; (iii) their opinions of the Motorway Service Areas; and (iv) their opinions of Blue-Green Infrastructure.

Background Information

The questionnaire was distributed at Gloucester MSA (Northbound and Southbound), over two days during summer 2016. A weekday, including mainly morning and afternoon commuters (a cool and overcast day), and a weekend, including mainly families and leisure motorists (a hot and sunny day), were chosen. A total of 86 respondents (42 male and 44 female) between the ages of circa 18 and 80 years fully completed the questionnaire, which included a wide range of visitors, with purposes of travel ranging from leisure to commuting.

Opinions of the Environment

Of the participants, many (88%) believe climate change poses a major threat to the UK, but only 76% have a personal concern, however there was consensus about the frequency of extreme weather events in the UK, with 84% agreeing that there has been an alarming increase, but only 70% recognising this as a personal concern. Flooding seems to be acknowledged as the major

climate change consequence within the UK (agreed by 95% of participants) however only 69% agree that they are worried about flooding.

Opinions of the Motorway Service Areas

Public opinion was very supportive of the design and presentation of the amenity building and surrounding landscape, with 100% of participants agreeing or strongly agreeing that the Gloucester Motorway Services Areas blend effectively with the surrounding landscape, and the majority (68%) being aware that they have been designed to minimally impact the environment. A greater number of female participants (75%) confirm an awareness of the site's environmental attributes as opposed to only 60% of male participants. Furthermore, 85% of those who are aware of the site aim of minimising impact on the environment live within a 50 mile radius, with only 48% of participants from outside a 50 mile radius having an awareness of the site's environmentally-friendly design features. Overall, 94% of all participants believe that other motorway services areas should be designed or adapted to look like Gloucester MSA.

The positive comments from participants about the aesthetics and environment were overwhelming, with comments including "it's like a hobbit house" and "an oasis compared to other MSAs". One participant even noted that he loved it so much he had taken his wife there on a date, and several queried why there was no signage on site to explain the 'eco' features.

Opinions of Blue-Green Infrastructure

Of the participants, many (89%) agree that the green roof, ditches, pond and wetlands enhance the MSA, however only 58% agree that the block paving used for the parking and walkways enhances the site aesthetically. Only 31% of participants agree that the block paving actually adds benefit to the environment, however 81% agree that the green roof provides environmental benefit and 89% agree that the ditches, pond and wetland are also environmentally beneficial. Similarly only 27% of participants agree that the block paving promotes rainwater soak-away (as opposed to 74% appreciating the function of the green roof and 39% understanding the purpose of ditches, pond and wetland as rainwater buffers). This leads to the assumption that favourable public perceptions are more likely to be influenced by nature.

Ultimately, the public expressed a preference for a greener, more aesthetic form of construction; however, they were seemingly not always able to make the connection between attractive green features and sustainable drainage (55% of participants being unable to either agree nor disagree as to whether the ditches, pond and wetland act as buffers to slow rainwater run-off). Only 53% of participants agree that the ditches, pond and wetland can help to control site pollution and as little as 20% are aware that block paving can help to control site pollution as part of a SuDS management train, indeed 42% of participants are neither able to agree nor disagree whether the block paving actually promotes rainwater soakaway. Overall, 64% of male participants feel that they are poorly informed about "Blue-Green" drainage systems, compared with 59% of female participants. As a result an increase in education about recognising and interpreting sustainable drainage systems is required in order to fuel a public demand for a move away from the traditional mains pipe network. From public opinion, it was apparent that demand for Blue-Green drainage was high (86% of participants want to see these

systems used in their neighbourhood and 89% believe they can reduce flood risk, with 72% in agreement that sustainable drainage components promote ecological biodiversity). 75% of participants want maintenance to be put into the domain of their Local Authority despite only 23% believing that sustainable features such as green roofs, block paving, ditches, ponds and wetlands are probably hard to maintain.

DISCUSSION

Public perceptions of SuDS are an important indicator of the level of knowledge about these types of system; however, perceptions may not be easy to gauge, especially when SuDS components are often concealed (Sayers, 2012). Implementing a shift away from hard 'grey' infrastructure requires the involvement of all stakeholders, including affected public, in developing new practices and behaviours to ensure functionality and sustainability (Everett *et al.,* 2016). The importance of public support for the implementation of any community project is crucial and understanding public opinion can provide information about what the general population value the most (Sanchez Lopez, 2014).

SuDS can strengthen communities by providing a focus for environmental education and public engagement in environmental protection in a localised area, whilst supporting development resilience to climate change and development pressures (Daly *et al.,* 2016). By introducing water to the urban environment the planning process provides an opportunity to place SuDS within the public arena, addressing the aspirations of the public for a better, cleaner and greener urban environment (Dickie *et al.,* 2010). Ponds and wetlands can be assets to the community, enhancing the quality of life, by providing attractive and tranquil green space within the built environment (Cahill, 2012). Wetlands can attract diverse wildlife species and ponds, with the inclusion of footpaths, benches and picnic tables, can provide attractive community areas to enable social cohesion (Dickie *et al.,* 2010).

Every aspect of SuDS development requires critical thought and it should be integrated into all types of construction (Illman, 2016). A big push is required by construction professionals and the general public to influence the government to do more to produce SuDS legislation (Corner, 2016). There is currently no one to champion the use of SuDS in the UK, or to raise public awareness of their benefits (Bray, 2016). There is both a lack of effective legislation and a low level of public demand which both need to be urgently addressed (Illman, 2016).

Local Authority Planning Departments are not embracing SuDS in developments through a lack of skill, poor policy base, reduced funding and minimal understanding of these systems. This has led to Local Planning Authorities being defeated by developers on appeal (Illman, 2016) and, therefore, the pattern of low delivery on these schemes is maintained, perpetuating poor public awareness (Corner, 2016). There is a great deal of societal malaise and general disinterest in sustainable drainage systems. The public do not appear enthused or interested in changing to a natural solution for managing rainwater simply because they are not making the connection to play space, green areas and bio-diverse wetlands and habitats (Bray, 2016).

Barriers preventing the uptake of SuDS, such as ongoing management and maintenance of public areas, need to be highlighted, worked through and resolved (Illman, 2016). To help gain support for future flood prevention initiatives, it is crucial for local communities to plan for the likelihood of flooding happening and the impact it will have as and when it does happen (Sayers, 2012). A centralised framework must be put in place surrounding the adoption of SuDS by Local Authorities, instead of each LA pursuing its own agenda without referral to central guidance. LA's would generally prefer for Water Companies to adopt and maintain SuDS areas, however as profit-making organisations there is limited incentive for them to do so (Corner, 2016).

There is minimal concentration on "amenity", and especially the engagement of local people in embracing and taking responsibility for improving their neighbourhood (Singleton, 2012). This form of surface water management has not been embraced fully by the public, to include the contribution SuDs provide to place-making and the environment (Shaffer, 2016). In areas where the public appeared to be well informed, they also viewed drainage schemes much more positively than in areas where little information had been made available (Apostolaki and Jefferies, 2005). In areas of the USA, such as Orlando, the signage is excellent, however in the UK there is a reluctance to specify or pay for signage. The client generally does not see signage information as valuable and, quite often, feels that SuDS simply "*foisted upon them by Planning Authorities*" (Bray, 2016).

CONCLUSIONS

Blue-Green systems mimic natural drainage processes to reduce the effect on the quality and quantity of run-off from developments and provide amenity and biodiversity benefits. However, embracing these changes and developing the techniques required to construct and maintain SuDS brings with it the opportunity to achieve important environmental and economic benefits through a more effective and sustainable model for the management of storm drainage. SuDS must be considered as "rainfall management" and not as drainage. When the term "drainage" is used, it is considered uninteresting and the public become disengaged.

There is a growing acceptance that we need to develop a more sustainable approach to managing surface water to ensure water quality and reduce reliance on limited sewer capacity, especially with the increase in frequency of severe weather events. There is very limited critical thinking as SuDS are in conflict with conventional drainage. The public must be made to understand that, unlike for sewage, pipes do not have to be the favoured conveyance channel for rainwater.

A SuDS scheme aims to do more than just deal with surface water problems. It is a relatively new and, for some, revolutionary way to seize opportunities with water. Planning requirements should dictate that there has to be SuDS interpretation boards and a budget for P.R. to highlight/publicise SuDS within a development in an effort to increase visibility and boost public demand. An entirely visible process must be engaged as it is critical that people make the connection and understand what SuDS components are doing/how they are linking. Public awareness will help promote the acceptance and use of these systems and encourage a new way of thinking. Public education in the field of stormwater pollution and management must also become an important contributory factor in the public demand for SuDS.

At Gloucester MSAs, it was overwhelmingly apparent that the public wanted to see environmentally-friendly forms of construction, and were enthusiastic about the aesthetics of the site. It was also evident that visitors were not consistently forming a link between the look of the MSA and the way it was sustainably managing rainwater, despite the design intention for the landscape to be readily understood. Public education can have a critical role in influencing acceptability of new or innovative practices; therefore, without further education about the benefits of blue-green infrastructure the general public will not be able to demand the sustainable rainwater management systems that underpin the aesthetic forms of construction they enjoy.

RECOMMENDATIONS

- There needs to be greater public awareness and a burden of responsibility on the individual to influence a change in opinion, as well as a corporate responsibility.
- Developers should be required to include sustainable drainage, where practicable, in new developments, built to standards which reduce flood damage and improve water quality. It remains too easy for developers to connect to mains drainage if they argue effectively.
- Local Councils should be given responsibility for maintenance, subject to funding, of vegetative and soft engineered SuDS features meeting the criteria for adoption into the public realm. SuDS schemes generally involve costly ground works or take up large sections of land that could be generating revenue; there is also the perception of a high maintenance liability and overall lifecycle costs which are perceived as a burden rather than a long-term permanent solution. As such there is limited competition for installing and maintaining, meaning that a standard framework should be developed.
- All organisations involved should introduce operational policy to facilitate the establishment of SuDS as the preferred method of surface water drainage for all new developments.
- SuDS planning must be made mandatory and included in every masterplan.
- Future Government policy should seek to increase the promotion of SuDS schemes, especially where new developments will impact on the surrounding area. This should include design and performance standards.

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THE DEVELOPMENT AND APPLICATION OF AN INNOVATIVE RAPID ASSESSMENT TOOL FOR FLUVIAL-FLOOD VULNERABILITY ANALYSIS

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Abstract

Demographic transition has resulted in encroachment and change in land use for some areas prone to flooding. Furthermore, climate change and associated flooding have meant an increased demand for improved flood impact assessment and its understanding so that socioeconomic and environmental impacts are mitigated. This paper proposes and evaluates the application of a novel Localised Rapid Flood Vulnerability Index (LRFVI) as applied to a specific locale in Somerset, UK. The final vulnerability assessment for this case study location ranged from 7 to 21 and was banded under 5 categories: very low/low/medium/high or very high. Analysis demonstrated that the flood vulnerability was unique to an individual location, despite the flood risk being considered the same for identical adjacent properties. Interpretation of these findings provided an increased understanding of the interaction between the socioeconomic and natural environmental requirements and overall flood vulnerability at a localised level. This research also demonstrated the need for a rapid and cost effective flood vulnerability assessment tool at the localised scale. Further application of this indexing tool to a broader geographical level is advocated since it has an adaptable structure and is ideally suited to account for GIS modelling outputs.

INTRODUCTION

Background

Flooding is an important socio-economic and environmental issue in the developed and developing world (IPCC, 2014). In Europe historical flooding records have shown its devastation and impact on communities, the local and national economies, and off-course on the natural environment itself (Rojas et al, 2013; Lamond and Penning-Rowsell, 2014; Tezuka et al, 2014). The cost to the taxpayer of the 213 major flooding events that occurred in the European Union between 1998 and 2009 is estimated to be €52.173 billion and directly resulted in 1,126 fatalities. As an example, the UK's summer floods of 2007 cost in excess of €4 billion alone. Furthermore, these figures do not include the plethora of small scale hazards and insurance claims linked to flooding on an annual basis. Overall, flooding is the most financially costly and most frequent of all natural hazards facing Europe (EEA, 2010). Re-occurrence of such flooding

events and incidents is increasing due to the impacts of climate change and their related anthropogenic associations (Pall et al, 2011; Lamond & Penning-Rowsell, 2014; The Royal Society, 2014).

Recent research also suggests that flood hazard is increasing in both intensity and frequency. "Flood peaks with a return period above 100 years are projected to double in frequency within three decades" (Alfieri, 2015: page 1120). Also this projected increase will not be spatially or temporally uniform in nature. Hence, there is a critical need to develop a rapid means to measure the flood vulnerability of regions, communities and individuals. This paper develops one such rapid vulnerability assessment tool and demonstrates its application on a real-world scenario located in Somerset, UK.

Current state of flood insurance

Current flood assignment in the UK uses Environment Agency (EA), Natural Resources Wales (NRW), and Scottish Environmental Protection Action (SEPA) flood maps as well as hydrological modelling systems as part of the internal assessment process of the UK insurance sector. Locations labelled high risk have a 1 in 100 or greater chance of flooding, reflected in higher premiums and reduced excess insurance rates. The previous UK flood insurance situation was declared unsustainable, and in 2015 a new flood re-insurance scheme, known in short as the "Flood Re Scheme", was introduced nationally (ABI, 2014). However, recent research highlights the problems associated with flood insurance schemes including underfunding in general, and an increasing encouragement to develop within flood prone areas (Burby, 2001; Gray, 2014).

The detailed investigation of an individual UK location's flood risk is currently carried out by completing a Flood Risk Assessment (FRA) which is now a legal requirement for any development that falls under specified criteria (Crown, 2014). FRA's actively aid in reduction of insurance costs via identification of resilience/resistance levels, and by proposing modification measures and assessing overall risk. However, FRA's can be costly, time consuming, unnecessary, and are not a failsafe system (BBC, 2013; Pardoe et al, 2011; McCabe, 2013; Maude, 2014).

METHODOLOGY

A new approach - Localised Rapid Flood Vulnerability Index (LRFVI)

The relationship between flood risk and flood vulnerability and their definitions alter depending on exact context and use, therefore clarity in precise usage and definition of precise terms is essential (Table 1). Flood risk in England is largely specified via flood maps produced by the EA. However, this does not indicate which specific receptor in the flood risk area will be hit by floodwater, or by virtue of its individual characteristics (e.g. location, size, height, bunds, etc.) what scale of flood risk this constitutes as depicted in Figure 1. Thus, the actual degree of vulnerability of a specific receptor can vary depending on the way it is being considered under a risk analysis i.e. resistance and vulnerability are inversely related (Table 1). This is referred to as the degree of vulnerability of that specific receptor, which may itself be a single building, a

house, a neighbourhood, or an entire community located in the flood risk area. Hence, the exact approach and proposed methodology being advocated in this paper focuses on a tailored vulnerability analysis carried out at the appropriate level and scale. This subsequently avoids the current system of applying a 'blanket' approach to flood risk assessment. It is anticipated that this innovative approach (i.e. flood vulnerability assessments favoured over current flood risk assessments) could also save time and effort while still proving more effective than traditional methods of assessment.

In this paper, flood risk is defined as the hydrological assessment of the areas topography, largely provided by the EA's flood maps, which themselves are limited in context as they do not determine a locations precise flood vulnerability to any defined flood risk. To establish a location's precise flood vulnerability, factors unique to the individual location need to be considered that alter the exact level of resistance of the specific location to the ingress of flood water. These will be considered in the next section.

Factors and parameters used in the LRFVI

Description of parameters

The proposed list of factors that relate to flood vulnerability are divided into four main parameters. Parameter A refers to an assessment of the location's external flood defence limit. It also identifies any subtle changes within the location's boundary that affects flow of floodwaters and identifies any barriers that increase flood resistance. Parameter B assesses topography and water management occurring just outside of the location's boundary. Identification of natural and anthropogenic topography and any subtle changes that alter the path of floodwaters entering the location will result in increasing or decreasing resistance to flood water of the locality. Parameter C identifies the presence of any nearby national flood defences. Assessment via a combination of flood risk maps provided by either EA, SEPA (dependant on location respectively) and NRW TAN 15 (Technical Advice Note 15: Development and Flood Risk 2004) when coupled to data provided by Google Earth, Street View and on-site observations as to whether or not the location is serviced by community flood defences will all together provide a relatively strong scoring for this parameter. Parameter D uses current flood risk designations as set by either TAN 15 (Wales) or EA maps (England) for this specific location and is scored accordingly within the proposed matrix. Two additional parameters are proposed that may be used in specific locations and instances. The first is Parameter E which is simply an additional scoring factor that is added when the combined parameter score of A+B+C+D = 16+. This parameter is in-line with the one used in the Palmer et al, (2011) method, which gives an additional weighting of 4 to the total score of earlier parameters so as to highlight the most vulnerable of locations. The second and final factor is Parameter F, which is only applied when known historical flooding of a location is present in significance. It is proposed that these devised list of factors and parameters would be regularly critically assessed and reviewed by experts within the flooding and insurance industry thereby ensuring their relevancy and validity for usage. Thus the methodology proposed here is a further adaptation from the Palmer et al, (2011) method, and it has enabled the development of the LRFVI formula and matrix (Tables 2 and 3).

Devised social, economic and environmental features and sub categories

The Palmer et al, (2011) method specifically investigates the social, economic and environmental (SEE) vulnerability of the coastline. Hence the addition of this further concept is also proposed under this novel methodology. So an identified list of SEE locations and land uses affected by flooding will be compiled from varying sources and via desktop/field studies observations (Ketchum, 1972; Crown, 2004; Pitt, 2007; Palmer et al, 2011) with further assessment by experts within the field to ensure relevancy and validity for usage. The lists produced are non-exhaustive, but provide examples of the eight main sub headings of SEE features found within all flood risk zones.

Development of the LRFVI scale

A pilot study conducted on the lower section of the Clyne River, Swansea, provided development of the scaling system required to produce the final vulnerability rating (Figure 1), prior to its actual application within the Queen Camel and Burrowbridge locations in Somerset, UK. A standard statistical analysis of the study data (composed of sixty seven samples) from the Clyne River site produced a final score value of LRFVI ranging from 8 to 21, with 8 being lowest and 21 the highest vulnerability score possible. A typical value returned was 12, with a mean value of 12.5, a mode value of 12, and a median value of 12. Production of the final index scale required development of a unique alternative method befitting the broadest of flooding contexts when compared to that of original Palmer et al, (2011) method which only focused on coastlines.

On analysing the River Clyde data, identified changes in the level of resilience/resistance of features occurred at specific points within the scoring scale. It was noted that significant differences in vulnerability occurred between scores of 10 and 11, due to an increase of vulnerability relating to one or more of the four parameters. Further changes in flood vulnerability occurred, with increasing vulnerability observed between scores 12/13, 14/15 and 16/17 respectively.

Utilising this natural correlation of change in vulnerability, it was possible to create the LRFVI scoring scale from which to assign the final vulnerability rating of any location (Figure 1). When cross referencing with the corresponding flood risk assessments made by the EA and TAN 15 flood risk maps, a score of 12 was confirmed thus returning a low flood vulnerability on the proposed LRFVI rating scale.

LRFVI scale devised from pilot study: Lower Clyne River

Sample size 67 locations

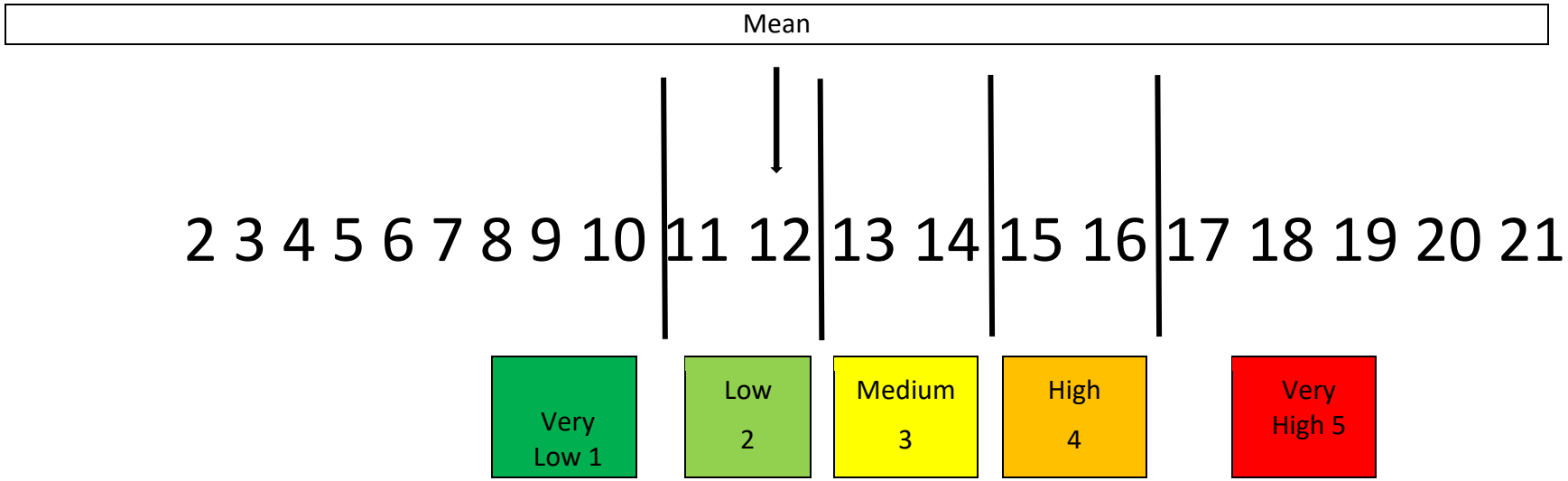

Figure 1 Localised Rapid Flood Vulnerability Index - vulnerability scoring scale7

Application of the methodology

Queen Camel

LRFVI test results from the first case study zone sited at Queen Camel showed that 7 of the 305 locations assessed are sited within very high risk areas with 17 sited within medium to high flood vulnerable areas. Evaluation of associated socio-economic and environmental usage enabled identification of the two locations scoring very high in vulnerability, namely, the school car park and the A359 High Street road, of SEE category 8. The land usage of these sites provides increased resilience, by requiring minimal mitigation to enable rapid re-use after floodwaters have receded. In contrast, the remaining locations sited within the higher risk sites comprised residential housing, business offices, other infrastructure and agricultural installations. The location of the school, electricity sub-station and the two residential properties, Mildmay Orchard and Milestone respectively, and located to the west of the main High Street A359, all scored medium and high vulnerability values respectively. This is indicative of flood plain land sited next to the River Cam that flows to the north of the village. The location of Mildmay Orchard, although obtaining medium flood vulnerability, has historically been inundated four times by floodwater since 1986. In response installation of flood resistance barriers up to one metre in height on the exterior of the property have been implemented (Anon, 2014). These external resistance improvements are reflected within the LRFVI by reducing vulnerability scores when compared to the neighbouring locations of the school and various residential properties whose own scores vary from high to medium.

The majority of residential properties scoring medium and high values are long established within the village, and prior to modern day planning regulations. The location of the older properties on the eastside of High Street road, surrounding the village Church, is consistent with historical settlement patterns observed in this local region, with siting of the actual Church being on much higher grounds (Lorenz et al, 2001; Victoria County History, 2014).
This is represented collectively by lower vulnerability score values.

New developments within closer proximity to the river and within its floodplain have occurred in recent times via the conversion of farm buildings. Indication of the extent of this natural floodplain is further established by the presence of a designated floodplain to the north side of the river. Representation of this fact is shown in the final scoring system, since there is a reduction of vulnerability appraisal from high to medium, thus mitigating the effects of any small scale flooding. The presence of high values obtained for Parameters B and D is indication of potential for flooding of the area, and it is confirmed via identification of historical flooding of these locations. The LRFVI clearly identifies via high Parameter B, C and D values for four locations situated within an area that serves as a natural floodplain separated by High Street road. Using a cost benefit analysis, interpretation of the Parameter C values within the medium to very high risk areas seem to advocate the against of implementation further flood protection measures as practical solutions.

Extensive housing development encircles the original village. The individual low scores seen in Parameters B and D indicate the areas chosen for development have naturally low flooding

potential with 93% of locations assessed obtaining very low and low vulnerability ratings, indicating appropriate sighting for this intended land usage. The location of the new medical practice, under category 8 infrastructure, is as expected sited within an area of very low vulnerability that complies with current planning policy requirements. The fields to the west of the A359 bridge over the River Cam are evidently the continuation of the floodplain for the river that have been developed within the village vicinity. In summary, the Queen Camel data clearly demonstrates the identification of individual location's vulnerability to flooding changes despite there being no change in assigned flood risk.

Burrowbridge

Burrowbridge village situated just above sea level and straddling the River Parrett, is comprehensively protected by extensive flood defences in the form of dykes, levees and ditches. They safeguard against overtopping of the River Parrett and against any surface water flooding. This has resulted in an overall reduced flood impact and flood vulnerability for the entire area.

Represented within the individual parameter scores, the majority of locations obtain low and medium scores. The occurrence of large quantities of high score values (of 3 and 4 respectively) for Parameter B is a definitive indication of the area's natural topography lending itself to flooding. Parameter C values demonstrate the level of defence's implemented already that enabled development of valued assets such as homes and businesses. Parameter D scoring (within an official EA flood zone), returning low values is clearly linked to Parameter C as the increased river defences have reduced the overall flood potential of the area as established from this desktop survey. Further evaluation of the data indicates the area is of high flooding potential since it is the natural floodplain for the River Parrett and the surrounding Levels. The scoring for Parameter A also suggests that the majority of locations, being housing developments, have relied solely upon government maintained flood defences and flood risk assessments. No indications of any extra resistance measures being applied to individual locations is evident despite them being located in such a vulnerable area prone to flooding.

Separated by the River Parrett, Burrowbridge's North river bank naturally sits higher than the South, resulting in the South side being served by greater defences, in excess of two metres in height. This results in the North side receiving less protection and higher Parameter C scores based on river defences alone, despite both riverbank tops being of identical height on both sides. During the 2013/14 period of extensive flooding, the Parrett River was inches from completely overtopping the defences on both sides of the river, but the South side of the river was flooded by surface water encroaching from the lower areas of the Somerset levels (Figure 2). This was taken into account during the field survey with the same stance as that of Parameter A being applied to Parameter C, i.e. using the lowest place any ingress of water can originate from as being used when assigning a relative index score. The fact that there is little in the way of protection from surface water flooding arising from the Somerset levels, thereby only accounting for the substantial defences in place for the protection against river flooding, would collectively produce an unrepresentative vulnerability score of 1 for Parameter C for all the south side locations. Assigning this relative score value to the lowest point of protection

results in improved representation of true vulnerability to flooding for a specific location, that also incorporates all sources of flooding and local defences.

Figure 2 The small community at Burrowbridge on the Banks of the River Parrett is completely surrounded by water (SWNS, 2014)

The most vulnerable, but resilient of locations are the main trunk roads running through the village. This is as expected since there is no protection and they run through the lowest parts of the area. Identified in the survey area are three places rated as SEE category 2 with scoring of high vulnerability, all located within a high risk area along the A361. The impacts of actual flooding (Figure 2) resulted in the closures and eventual relocation of businesses that were once located on the New Road A361 (Morgan, 2013). The same is observed on the Stathe Road with the siting of two SEE category 2 locations that were also flooded in 2013/14, albeit to a lesser extent.

Once again the flaws of using the outputs of a flood risk assessment to blanket cover a wide area is clearly exposed in the Burrowbridge data set. For instance this shown by the location of Dyke House on Riverside Road that specifically scores very low when compared to the surrounding medium vulnerability locations, since its specific Parameter A score is 1. This reduction of vulnerability is due to this particular dwelling being constructed on higher ground than that of the surrounding land and neighbouring locations. This clearly demonstrates individual change to flood vulnerability does occur even with apparent unchanged flood risk.

DISCUSSION

Observations within the recorded data

Interpretation of the corresponding parameter score values ranging from 1 to 4 reveals certain trends and occurrence combinations that give insight into the land surveyed and its flood risk perception (Table 4). Data analysis identifies high score occurrence of Parameters A and B with lower scores for Parameters C and D respectively, which indicates these areas are served by a form of flood defence with the local topography being prone to flooding. High Parameter A scores in this specific scenario indicates there is a reduced perception of flooding risk, since no individual action has been taken, with an increasing resistance to flooding. In these cases reliance is upon national defences alone, as has been documented in similar case studies completed in the Netherlands (Baan and Klijn, 2004; Botzen et al, 2009). The opposite is observed within this data set as well with some areas having low scoring Parameter B and D values, coupled with a high Parameter C score of 4, collectively implying the area is not liable to flooding. The occurrence of this combination of scores is anticipated when assessing new land development for structural and socio-economic use (Crown, 2012a), since these identified areas usually are of very low or low vulnerability.

As such there is also a middle ground of scores observed in these data sets. It was expected to observe a reduction in Parameter A scores relative to an increase in Parameters B and D ones. This was observed in a limited number of locations, implying a reliance on national defence rather than individual resistance, and a reduced overall flood risk perception. This outcome further supports the work of Bann and Klijn (2004), Botzen et al, (2009), and Botzen and Bergh (2012), who all observed the Bayesian theory of a reduction in overall perceived flood risk being relative to the reduction in flooding episodes over time due to implementation of national defences.

In addition to its suitability as a rapid assessment method for individual location's, extensive long term assessment of these same locations, usually spanning decades, would provide insight into the changing vulnerability of individual locations and the surrounding area to climate change effects, which is more akin to the original usage of these proposed vulnerability indexes. Hence this would assist in providing more realistic data to calculate flood insurance risk relative to the location's unique conditions.

Analysis of raw data and observations made during the site visits shows the locations of low scoring (i.e. 1 and 2) for Parameter A is either the result of construction upon raised up ground within its location boundary, or selected sites being in an area with naturally higher levels of topography in relation to the surrounding land and thus placing them beyond atypical flood levels. The exception to this is seen in the Queen Camel data set with the property previously flooded, implementing several resistance measures. On the other had, when considering the potential risk to flooding that was posed in the Burrowbridge selected area, it was reasonable to assume that increased implementation of resistance measures to an individual location would have been observed. However this was not the case, furthering strengthening the proposed theory of sole reliance upon the government to maintain defence systems in an area.

Application of the LRFVI system

It is apparent that a key outcome of this study is that the LRFVI matrix provides valuable information relating to an individual location's vulnerability to flooding that echoes with the majority of flood zone assessments made by the EA and TAN 15 flood maps used within the investigation. However this index provides increased detail in comparison to the flooding maps through its ability to identify an individual location's unique resistance to flooding. This confirms the theory that the current approach employed within the flood industry is lacking in detail, since neighbouring locations can have differing vulnerability.

The use of the LRFVI within the land management sector, construction sector and consumer user sector would allow rapid evaluation of a location's vulnerability to flooding, permitting further designation of this land for appropriate use, i.e. if the LRFVI returns a high or very high vulnerability score, the location should not be developed for infrastructure of social or economic use that was not resilient or resistant to flooding. Alternatively, this implies the location could have value for social wellbeing and the natural environmental, as many floodplains are home to vast number of rare and endangered species and habitats, as was present within this study area of the Somerset levels and moors (Astell-Burt et al, 2013; Opperman et al, 2013; Kousky and Walls, 2014; Wolch et al, 2014). Thus this study indicates that the LRFVI method has the ability to be used on any location, regardless of current or intended use.

The rapid nature of this proposed assessment procedure allows a single location's vulnerability to be assessed within a much shorter time than that of a formal FRA, the wider benefits of which impact the private and commercial sectors by speeding up planning decisions and by reducing insurance costs for property owners. This index method would decrease the need to instigate costly and lengthy FRA's for locations with borderline flood risks levels.

With current methods assigning high flood risk based on the most at risk within a postcode area, and with the implications of changing land use and climate change effects, the potential for future increases in flooding of these locations necessitates continuing investigation. This is ever more important due to the potential for current and future insurance agreements to fail (Gray, 2014). With application of the LRFVI, current vulnerability can be assessed rapidly, with subsequent identification of the most likely locations with increasing vulnerability due to climate change effects. This would also provide ample time for appropriate mitigation to be implemented, thus reducing pressure on an already strained UK insurance system while increasing overall resilience of the country. However, the drawback of actively reducing flood vulnerability can create multiple conflicts (Kousky and Walls, 2014; Matulis, 2014; Pardoe et al, 2011). Despite enabling a continued ability to obtain low cost flood insurance and continued use of the locations, an overall reduced vulnerability can cause a schism with the actual flood risk posed. On the other hand there is the potential of increasing perceived socio-economic value of a location (Mount, 2014).

CONCLUSIONS

1. Addressing weaknesses within vulnerability indices is key to producing a rapid assessment method. The method developed by Palmer et al (2011), being validated and reliable, provided fundamental structure required for this study and eliminated a number of issues identified. Combining the SEE assessment method is beneficial since it allows quick cross analysis of locations within highly vulnerable locales through basic data analysis coupled with improving understanding of land use.

2. Although the fundamental structure of the LRFVI is not new, its application for assessing flood vulnerability from the aspect of a specific location is unique within current theory and practice. The factors, parameters, matrix and scoring system are unique to this study, with the LRFVI providing representation of flood vulnerability regardless of the level of flood risk actually assigned.

3. The LRFVI efficiently identifies any natural or developed location within high risk areas that have the ability to be resistant to flooding and the level of resistance that is present, all represented as a vulnerability score. The impact of this approach has the potential to be both negative and positive in outcome, for identified within the data are number of locations classed as having the same flood risk, but have varying levels of flood vulnerability. With all locations having >1% risk of flooding in any given year classed as high risk, the combination of the LRFVI with current EA/NRW and internal company flood risk maps would enable more reflective flood insurance without the need for bespoke FRA's to be carried out on a location with borderline >1% risk. Additionally, the use of the LRFVI would further justify the need for FRA's on the locations that require them, potentially giving the location a combined high flood vulnerability and risk value, thereby increasing cost of insurance.

4. The LRFVI provides an economic incentive to improve resistance and resilience to reduce overall insurance cost, since it assists in alleviating problems associated with perception of real flood risk. Analysis of Parameter A and B scores allows quick indication and direction of areas required for further improvement, potentially removing the need for an expensive and lengthy FRA.

5. Through further data analysis and remote systems analysis using GIS modelling, it is feasible for the overall flooding vulnerability of a geographical area to be obtained, thus maintaining each individual location's status. When combined with flood risk maps, this would enable a detailed picture of the urban sprawl's evolution and areas affected by flooding, and how development was progressing and adapting within flood prone areas.

6. Current land usage and perceived value requires further investigation since any increase in perceived economic value of an area subjected to regular flooding may encourage use of land otherwise deemed unsuitable for development. This brings into question whether locations should be left as part of the natural environment, thus providing important havens for wildlife. It also brings into question how we comparatively value socio-economic and environmental location usage.

Conflict of Interest

All the authors confirm that there are no conflict of interests associated with this work or this publication.

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Appendix: Tables

Table 1 Definitions of terminology used within the paper

Risk	The possibility of exposure to harm or damage from a hazard i.e. EA defined flood risk as the probability of a flooding episode of varying magnitude to affect a location
Vulnerability	Lack of capacity to resist inundation of flood water
Flood/Flooding	Any source of water that can inundate a location with the potential for damage
Resilience	The ability of a location to be inundated with flood water and return to its normal state
Resistance	The degree to which a location can halt the ingress of water that would cause damage.

Table 2: LRFVI Formula

Relative Localised Rapid Flood Vulnerability Index formula
= A + B + C + D + E + F
A=Location External Defence Limit, B=Local Topography/Water Management reducing flooding, C=National Flood Defence, D=EA Flood Zone Designation, E=Factor of 4 added to highlight flooding severity of location (if A+B+C+D=16) and F=Factor of 1 added to highlight historic flooding. This translates in to the ILFVI matrix as seen in Table 3.

Table 3: Localised Rapid Flood Vulnerability Index

Parameters	Extremely Low (Score 1)	Low (Score 2)	Moderate (Score 3)	High (Score 4)
A: Location External Defence Limit	> 1m	1 - 0.5m	up to 0.5m	No defence
B: Local Topography/Water Management reducing flooding	Very Good	Good	Average	Poor
C: National Flood Defence	>2m	1 - 2m	up to 1m	No defence
D: EA Flood Zone Designation	Very Low	Low	Medium	High
E: FACTOR OF 4 ADDED TO HIGHLIGHT FLOODING RISK OF LOCATION				
F: FACTOR OF 1 ADDED TO HIGHLIGHT HISTORIC FLOODING				
Score: Min 4 Max 16+4+1=21				
A+B+C+D+E+F=21				
Add E when A+B+C+D =16				
Add F when location has known history of flooding				

Table 4 Observed patterns within the parameter scores

Parameter A	Parameter B	Parameter C	Parameter D	Vulnerability Pattern
1	1	4	1	Very Low Flood Vulnerability
3/4	1/2	4	1/2	Low Flood Vulnerability risk
3	4	4	1	Medium Risk in matrix / low on EA flooding map
1/2	3/4	1/2/3	1/2	High Flood risk potential with National defence and high flood risk perception
3/4	3/4	1/2/3	1/2	High Flood risk potential with National defence and low flood risk perception
4	4	4	4	Very High Vulnerability

DRIVING EFFICIENT INFORMATION MANAGEMENT THROUGHOUT THE WHOLE LIFE CYCLE OF CONSTRUCTION PROJECTS: TIER 1 CONTRACTOR'S CONTRIBUTION TO REAL VALUE CHALLENGE TO SUSTAINABLE DECONSTRUCTION PROCESSES.

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Keywords: Building information modelling, sustainable deconstruction, asset information model, whole life value

Abstract

Recent developments in information management in the UK construction industry have promoted effective project team collaboration. Whilst the 1192 standards introduced by the UK central government for Building Information Modelling, BIM Level 2 adoption directly address information management during the design, construction and operation phases, no similar standard has been produced to deal with information management at end of life processes. Absence of a standard to regulate information management at demolition and asset disposal phase implies that the whole life value sustainability loop using the above 1192 standards cannot yet be appropriately closed. This paper argues that BIM should not end at the maintenance phase, but should be extended to the demolition stage to promote sustainable deconstruction processes. Using quantitative structured questionnaires and in-depth interviews, findings gathered from key project members of a tier 1 contractor on 3 education projects in the UK, commissioned to BIM Level 2 requirements, this research established how current site processes lack a systematic way of data capture and information management aimed specifically to support sustainable deconstruction. Furthermore, the research concludes that only through standardised and regulated site installation approaches can the retrieval and repurposing of the BIM Construction Operations Building information exchange, COBie data in the Asset Information Models, AIMs, be extended for appraising the value of physical asset components for reuse at feasibility stages of future projects. This preliminary research provides the basis from which to further develop the BIM 1192 standard to guide a sustainable deconstruction process.

INTRODUCTION: The construction industry and the global economy in context

The construction industry in the UK, accounts for £90bn of the economy, which translates to 6.7% in value added and 10% of the total UK workforce, making it one of the largest in Europe, (Department for Business, Innovation and Skills, 2013). Defined as consisting of construction contracting industry, providing construction related professional services and construction related products the significance of collaborative working between the 280, 000 businesses which provide 2.93m jobs cannot be underestimated. (EC Harris LLP, 2013) Yet research by the UK central Government, the industry's largest customer with a 40% share (Cabinet Office, May 2011), shows the construction to be highly fragmented with many subcontracting relationships. (Mursell, 2018).

This high level of disaggregation in the construction supply chain provides for a culture of limited desire for meaningful collaboration. Effective collaboration between all stakeholders on construction projects is a requisite ingredient for attaining higher standards of quality and delivery

performance through optimisation of communication, data exchange, information sharing and information management at all stages during the lifecycle of built assets. (British Standards Institution, 2016) and (BSI Standards Publication, 2015)

Although recent developments in information management in the UK construction industry have promoted effective project team collaboration amongst the supply chain, more needs to be done to alter industry behaviours to facilitate a culture that addresses not just the capital delivery stage but promotes a holistic appraisal of built assets at all stages including the end of life processes. For example, following on from the publication of Government Construction Strategy in 2011, the UK central government introduced the 1192 standards to facilitate Building Information Modelling, BIM Level 2 adoption.

Whilst the above 1192 standards directly address information management during the design, construction and operation phases, no similar standard has been produced to deal with information management at end of life processes. Absence of a standard to regulate information management at demolition and asset disposal phase implies that the whole life value sustainability loop using the above 1192 standards cannot yet be appropriately closed. This paper argues that BIM should not end at the maintenance phase, but should be extended to assist design development for the disposal stage, be it demolition or preferably more sustainable deconstruction processes including options like re-use and recycling.

LITERATURE REVIEW AND OTHER SPECIFIC WORK DIRECTLY RELATED TO THE RESEARCH

Effective project team collaboration

Effective collaboration is best achieved by well planned, two-way communication between project stakeholders (Lancaster, et al., n.d.). This requires the ability to communicate, share and re-use data, or existing knowledge (BSI Standards Publication, 2015), with organisations having to look beyond their own needs, but to work in new collaborative environments and using new methods of procurement that favour partnering. The widely respected reports, The Latham Report, Egan Report and the Wolstenholme Review all advocate for a sustainable industry that reduces waste through collaborative working. (Redmond , et al., July 2012) extend the need for information exchange using cloud based platforms beyond just automating traditional paper based processes. BIM is one innovative way of managing design to achieve better project performance by facilitating the exchange of all types of information throughout the project lifecycle in a consistent manner. For example, by facilitating the ability to interrogate the virtual building for buildability, logistics, building performance analysis and life cycle costing BIM enables an informed and practical interaction between main contractor and supply chain prior to installation on site.

Information management during the design, construction and operation phases

(Winfield & Rock, 2018) identified the 8 pillars of BIM Level 2, and duly anticipated imminent publication of PAS 1192 – 6. These 9 pillars are listed in Table 1 below summarising the information management stages they cover. Although the above standards provide a framework for working in BIM, they do not provide a robust process for *what* information needs to be captured specifically for use and application during the asset end of life stage. This critically important but missing linking piece re-affirms the assertion from this research that no standard in the 1192 set has been produced to specifically address *how* information captured and stored during preceding stages in the lifecycle of a construction project is evaluated and linked to end of life information management for effective

re-use when a construction asset has reached its end of life. A standard specific to the end of life activities is required to allow for a clear, targeted unambiguous process for information management during that phase. Without such a document, the 1192 standards remain incomplete.

Table 1: 9 Pillars of BIM Level 2

Publicly Available Specification/ British Standard	**Primary project lifecycle stages addressed**	**Comments**
BS 1192:2007 + A2:2016 Collaborative production of architectural, engineering and construction information – Code of practice	☒ Design ☒ Construction ☒ Operation ☒ End of Life	Provides methodology for managing the production, sharing and quality of construction information in a structured way suitable for collaboration and a specified naming policy for all stakeholders at all stages of the project. Whilst it makes relevant reference to deconstruction, end of life is not the central theme.
Specification for information management for the capital/delivery phase of construction projects using building information modelling	☒ Design ☒ Construction ☐ Operation ☐ End of Life	Production of information in a standardised and structured manner to ensure use and reuse throughout the project and life of the asset. Although lean processes are targeted at creating value for the employer, this PAS does not specify what and how information specific for end of life is captured.
PAS 1192-3:2014 Specification for information management for the operational phase of assets using BIM	☐ Design ☐ Construction ☒ Operation ☐ End of Life	Focuses on operational phase of assets, accurate, good quality, verified and complete information transfer at handover. Extensive reference to PAS 192-2 but does not make specific reference to how information in the operational phase should be used during the deconstruction phase.
PAS 1192-4:2014 Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie	☒ Design ☒ Construction ☒ Operation ☐ End of Life	Defines information exchange schema between employer and supply chain. The onus is on the employer to specify what information they require in an accessible way. Whilst there is ample opportunity for the asset owner, opportunities to specify what information is specifically needed for end of life processes is not clear.
PAS 1192-5:2015 Specification for security-minded building information modelling, digital built environments and	☒ Design ☒ Construction ☒ Operation ☐ End of Life	Recognises that increasing collaboration in the built environment necessitates the use of technology. However, asset owners and stakeholders need to understand the vulnerabilities and the controls required for security provision for the digital assets. There is no address of how or what information

smart asset management		required for end of life processes should be captured and stored.
PAS 1192-6:2018 Specification for collaborative sharing and use of structured Health and Safety information using BIM	☒ Design ☒ Construction ☒ Operation ☒ End of Life	Addresses information management specifically to improve Health and Safety standards by employing BIM processes and applications in order to reduce the potential for harm. Although Health and Safety will be pertinent for reuse or recycling of any construction components during the end of life stage this PAS does not address how the information is captured and stored
Digital Plan of Work Outlines information requirements for a constructed asset	☒ Design ☒ Construction ☒ Operation ☒ End of Life	Provides clarity on defining and testing and use of data by project stakeholders across all stages. It is not specific to, nor does it specify what information should be captured for end of life stage
Classification (Uniclass 2015)	☒ Design ☒ Construction ☒ Operation ☐ End of Life	Provides a common terminology and structure for project documentation, and allows for that information to be related. It is not specific to end of life only.
CIC BIM Protocol: Second Edition 2018 Standard Protocol for use in projects using BIM	☒ Design ☒ Construction ☐ Operation ☐ End of Life	Sets out a framework for contractual obligations for parties involved on BIM projects and in particular for design and construction phases (in line with PAS 1192 – 2). There is no specific reference to any information management requirements specific to end of life processes.
PAS 1192-X:20XX Specification for information management for the end of life phase of construction projects using BIM	☐ Design ☐ Construction ☐ Operation ☒ End of Life	Required to complete the whole life value using the 1192 standards. Particular emphasis to be on efficiency, construction quality improvement, optimised construction information management and data capture and recording to support data re-use for new projects

Information management at end of life processes, (demolition and asset disposal phases)

Whole Life Appraisal Tool for the Built Environment produced by the Scottish Futures Trust, promotes holistic appraisal of built assets at all stages including the end of life processes. Its ability to compare design options, materials or renewables before the actual construction process can be used alongside BIM for appraising buildability, to drive efficiency and improve data capture during construction. The resulting high-quality asset information models, AIMs, facilitate for the full life cycle assessment – whole life sustainability approach. The flexibility for adoption to suit various sectors, and for individual clients to tailor the tool to their specific needs sets the basis for the introduction of such concepts as Advanced Product Quality

Planning, APQP during the construction phase. The automotive and manufacturing industries have successfully adopted this way of working.
Evidence from (Scottish Futures Trust, 2016), (Bateson, 2015) and (Mursell, 2018), shows that achieving optimum outcomes for whole life sustainability becomes more realistic where client and his tier 1 contractor create a culture of shared risk and responsibility, adhere to a collaborative working environment from inception to completion, within a close contractual relationship that favours partnering. Furthermore, research shows that the greatest opportunity to influence sustainability is during early project stages of where decisions regarding an asset's maintenance and running costs are made. (Office of Government Commerce, 2007). Engaging a highly skilled design team that is well integrated with the project team creates an environment where all options available for consideration can be strategically and systematically appraised to optimise outcomes. Informed Clients who truly understand sustainability give financial and non-financial parameters equal emphasis when procuring projects, (Mursell, 2018).

RESEARCH REVIEW AND METHODOLOGY

To underpin this study a structured methodology was applied as shown in Figure1, below. Five key stages of study were followed as explained in the following section 'Research Method' and comprised both qualitative and quantitative surveys. The research was conducted to inform a tier 1 contractor's position in the current debate around collaborative working within the industry, the level and use of BIM technology and the examination of how the 1192 standards support whole life sustainability.

The research for this initial study was limited to a single tier 1 contractor organisation. This enabled the authors to complete a 'controlled' study on the focus subject without the added complications of dealing with different organisation structures and systems that could exist across projects being delivered by different contractor organisations. Even though the initial study was restricted to one contractor, the authors were able to assess responses in terms of relevance to the construction sector as a whole by matching back findings of previous researchers as identified through the literature review. Furthermore, the 5 steps of the initial study were designed to grow from a generalised survey through to more detailed and focused investigation. By completing the study in this way, it was possible to formulate an improved understanding of how well BIM and related information on COBie and AIMs were being deployed and used on typical construction projects. The methodology was appropriate to capture industry wide issues by focusing on one organisation to examine an area of profound importance that the industry is still grappling with.

Research Method

A structured 5-stage survey model (see Figure 1) was designed and applied.

The literature review of stage 1 enabled the authors to ascertain the historical and present day situation regarding research and developments within the field of BIM and use of design, construction and asset information. This identified the shortfall in closing the BIM-loop with regards to complete COBie and AIMs information and which would support re-use and repurpose of construction materials, components and structures. Findings from the literature

review helped shape the approach, scope and detail for the initial research surveys as applied through stages 2 to 5.

Stages 2 to 5 involved a structured combination of qualitative and quantitative questionnaires and surveys. Findings from each stage helped inform the scope, type and level of data to be captured in the next stage. Additionally, it was also possible to define the areas and personnel most appropriate to support the level of survey information sought. By applying this structured approach, it was therefore possible to retrieve the type and level of information in the most efficient and appropriate way for this initial research study. Figure 1 outlines the mode of information survey conducted at each phase. Preliminary results from this focused survey and interviews in the context of the previous surveys and literature review are discussed in this paper.

Figure 1: Research methodology

1. Literature Review

- 1192 Standards /Whole life value of construction assets/ Collaboration in construction using Building Information Modelling

To establish the needs for BIM implementation for a tier 1 contractor

2. Quantitative structured questionnaire + interviews

- Targeted at senior management within a tier 1 contractor organisation
- Survey scope: Establishing the level of implementation of technology and related tangible and intangible benefits on construction projects

Recommendations indicated a need for

3. Quantitative surveys

- Based on pilot projects
- Survey scope: To establish the level and type of information collected re use of BIM and creation of COBie and AIMs data as found on construction projects

Findings necessitated further information

4. Quantitative survey

- Targeted at wider business unit - 250 employees
- Survey scope: To establish the same as stage 3 but on a wider business unit basis + establishing how technology can help improve productivity through better structuring, management and use of project information

Further information required to get 'wider - project' perspective

5. Focus group surveys using case studies

. Targeted 13 site-based project team members on BIM Level 2 enabled construction projects, including personnel involved in post construction works

a. Survey scope: To establish the type of BIM information collated during construction and post project handover.

RESEARCH RESULTS

Senior management survey results

Seven responses from senior management indicated a good level of engagement and the desire to implement BIM, albeit in a structured but gradual approach including effective training. The findings are summarised in Table 2.

Table 2: Senior Management questionnaire

Selected questions from questionnaire	Key Findings
Q2. Section 5.3 of the BIM Strategy Document relates to Field BIM Mobile devices for use by site based teams. Do you consider the provision and use of mobile devices a worthwhile investment that you would support?	• signal and download speed and given the current size of files could be an obstacle • requires trial to fully understand benefits • access to information and better interaction with subcontractors • the technology needs to be fully tested and work • BIM cannot be embedded into the business if it is not there for the use of the teams on site.
Q3. What would you consider to be the current barriers to the use of mobile devices/ mobile technologies on site by site teams?	• poor connectivity • lack of understanding • easy user interface • poor choice of technology in the past • site team members need familiarity with mobile devices. • transitioning to platforms that interact with 3D models will further enhance mobile device usage by site teams
Q4 What do you consider to be the critical outcome, or key expectations on productivity by site based project team members that the use of mobile devices/ mobile technologies would bring?	• efficiency in day-to-day operations • allow linkages to the tasks such as permits, snagging, drawing review, programme progress etc • 3-D model to be primary project communication tool • time spent reviewing models is cheaper than site rectification. • Better capture of the site rectification work through the nonconformity route would allow the cost to be assessed against the project and a percentage produced. • reduce paper • speed of access to information • improved productivity

	• quality of the model/ the production of the model keep ahead of the pace of the work on site.

Technology pilot projects survey results

Following 6 months of initial training and hands-on technology usage on three pilot projects tangible and intangible benefits were compiled, and summarised in Table 3.

Table 3: Tangible and intangible benefits of using technology on construction projects.

	Summary Statistics from pilot projetcs					
Savings captured utilising Technology (A) tools (e.g. personal productivity savings, schedule accelerations savings, quality savings)	**Items Generated over 3 months**	**Traditional Way (mins)**	**Technology (A) Field (mins)**	**Time Reduction (hrs)**	**Total Time Savings (hours)**	**Notes comments from site teams**
Tangible Savings						Time savings realised based on feedback from site staff. **Detailed savings** and Financial benefits can be calculated based on these findings
Time required to run QA/QC checklists (Including photographic evidence and signature sign-off and report generation). Figures **based on 1 checklist**	80	20	5	75%	20.00	
Time required to duplicate handwritten field notes to PC or into a report (Based on 1 snags each with a photo or pinned position) Figures **based on 1 snag**	400	7	3	57%	26.67	
Time required to duplicate digital (MS Excel) notes into a report with photos or marked up snag position. (**Based on 1 snag with photos**)	400	5	3	40%	13.33	
Time required to complete daily site diary, including photos. (word documet, would type out at end of day at desk) **(Based on 1 Site Diary entry)**	215	17	5	71%	43.00	Built in weather information is great benefit. Photos and the automatic calculation of each subcontractor's time is very useful
Time of getting new snags/"issues" despatched to respective team members	400	5	1	80%	26.67	(Gather snags on laptop, in excel filter each company out, send email to Sub's Boss, print out copy and hand to sub) based on 5 mins/subcontractor.
Time needed to consolidate and summarise all trade issue logs or multiple versions of them into a single comprehensive report for PM (this is completed in above tasks) **(Based on 1 Progress Report per project per month)**	9	30	5	83%	3.75	Loads and loads of lists, and bring them all together. One room could take 10 min of time in field, then create a document, upload photos, email out = 30min / room
Time taken to develop and issue a monthly (or weekly) issue progress reports **(Based on 1 Progress Report per project per month)**	9	60	2	97%	8.70	(Ruben: Quality and Snagging monhtly reports. "Takes a ton of time", 15 min / room? "Several total hours, maybe all day"
Time of delay in tracking down missing information e.g. for O&M manual sections. (*Value indicated based on site team experience)	n/a*	30	4	87%		May have to look at drawing on screen, or have to wait for someone to drive to/from office or get off 4Projects.
Intangible Savings						
Protection against future claims as a result of improved record keeping						
Efficiency gains from technology use means time available to site teams to be used on other activities.						
Time savings related to Site Managers spending more time on the job face and not in the site office.						
Site Managers spending more time on the job face contributes to reduction in errors and re-work.						
Administration time required to create and deliver comprehensive organised reports						
Ability for project team members off site to view and see the current status of the jobsite						
Cost/time savings due to supervisors reducing escalation of avoidable issues to client representatives						
Overall time savings by site personnel, reducing the need for overtime and hence staff burn out.						
Benefits of presentation as a result of consistent reporting across projects						
Senior staff ability to view an accurate picture of issues status across projects/ time taken to respond to ad hoc status issues						
Team/ individual job satisfaction						
Time needed to consolidate and summarise all trade issue logs or multiple versions of them into a single comprehensive report for PM (this is completed in above task)						

Further interviews and discussions with project team members provided more details, some of which are listed below.

1. Improved efficiency, more detailed snags recording more accurate detail in capturing entries for site diaries, more efficient record keeping overall, less paper waste, less time spent printing.
2. Clearer presentation of snags to subcontractors including markers (pins) in plan, and photographic evidence of issues or quality checks. Reduction in time taken on the phone, or printing and collating information.
3. Innovation leadership – the site feels and looks better with being leaders in technology. Staying up to date with current trends in leadership is rewarding.
4. Ability for site managers/ engineers to spend more time on site means more time supervising site activities and ensuring it gets done correct first-time round.
5. Availability of information at the job face – ability to check drawings, photos, issues live on site allows site teams to access drawings live with the subcontractors to facilitate correct installations.
6. Cuts down on paperwork, site teams to do not have to spend time filing information later on paper. People off site can access and view the current project status.

7. The live recording of issues enables site managers to control quality and manage our subcontractors better.
8. Improved record keeping gives us better protection from claims.
9. Improved safety and production as site managers spend more time on site.

Results from the three educational case study projects

In order to start aggregating data that provides evidence supporting that construction projects are complex, require a holistic approach from inception to end of life processes, and that a tier 1 contractor can influence whole life sustainability, the more elaborate questionnaire structured in a

matrix format captured information from project team members working on BIM Level 2 projects. Key results are summarised below.

- Only a few have worked on BIM Level 2 projects. (Q2)
- Site teams mostly use a combination of hand written notes and some form of technology for site processes like site diary quality etc (Q3).
- Retrieving different types of information at different times after practical completion was overwhelmingly deemed to be "not easy" thereby posing the most significant challenge. (Q4)
- Survey results also show that site teams consider the use of technology for various site processes to be "highly significant" and "significant" (Q5)

Figure 2: Findings from question 3.

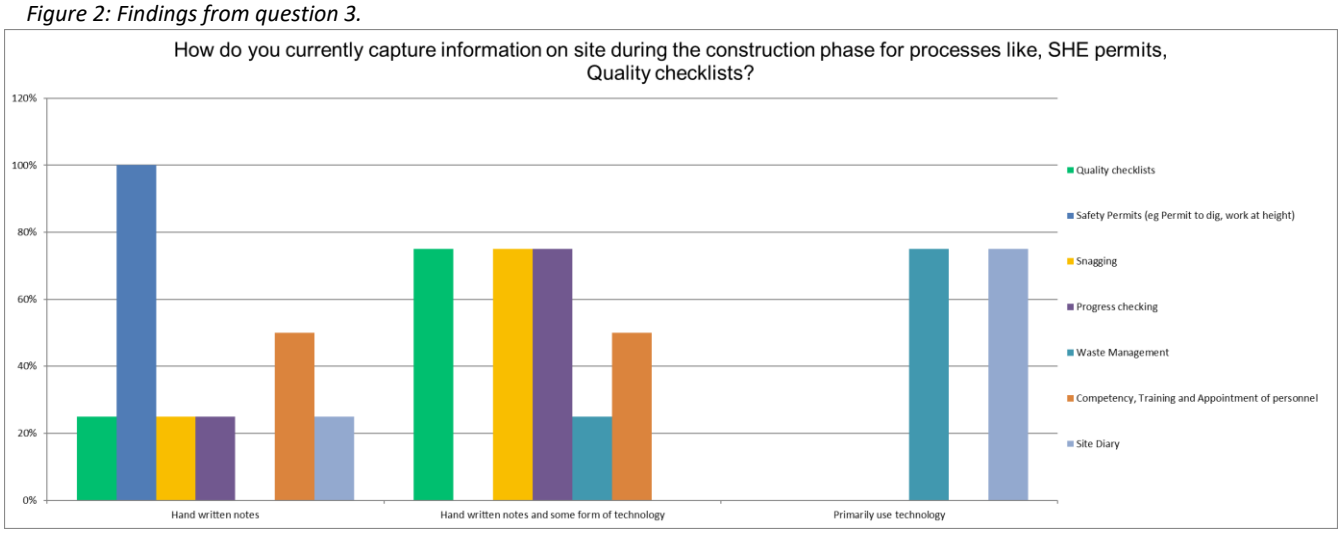


Figure 3: Findings from question 4.

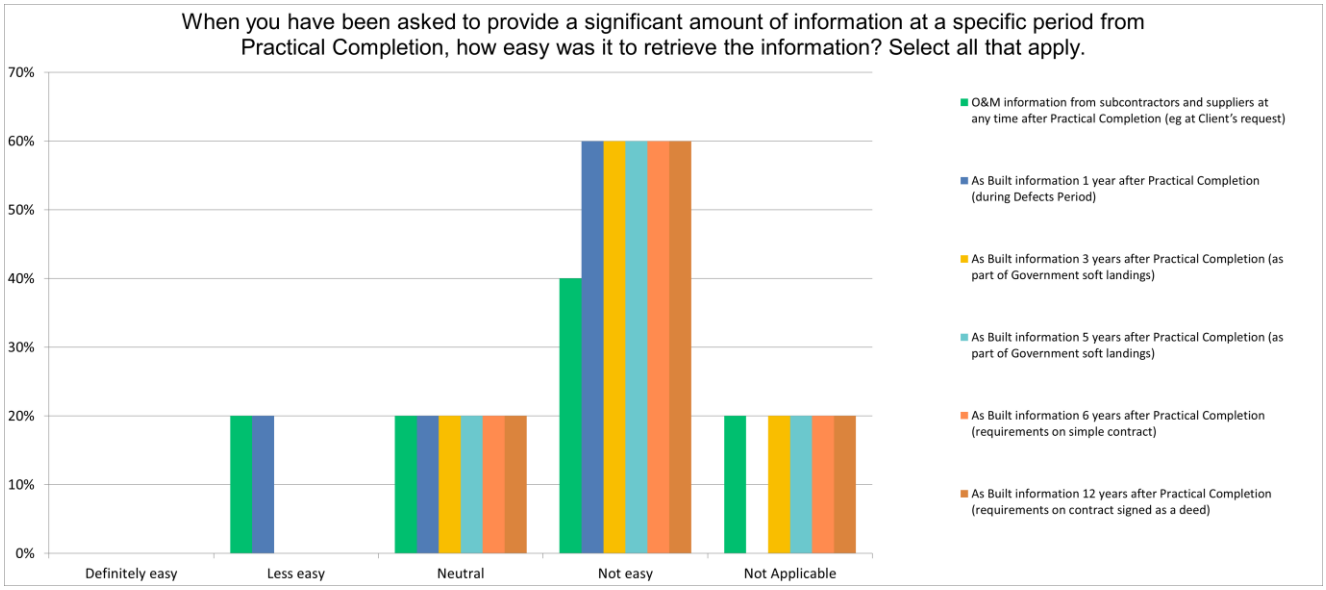
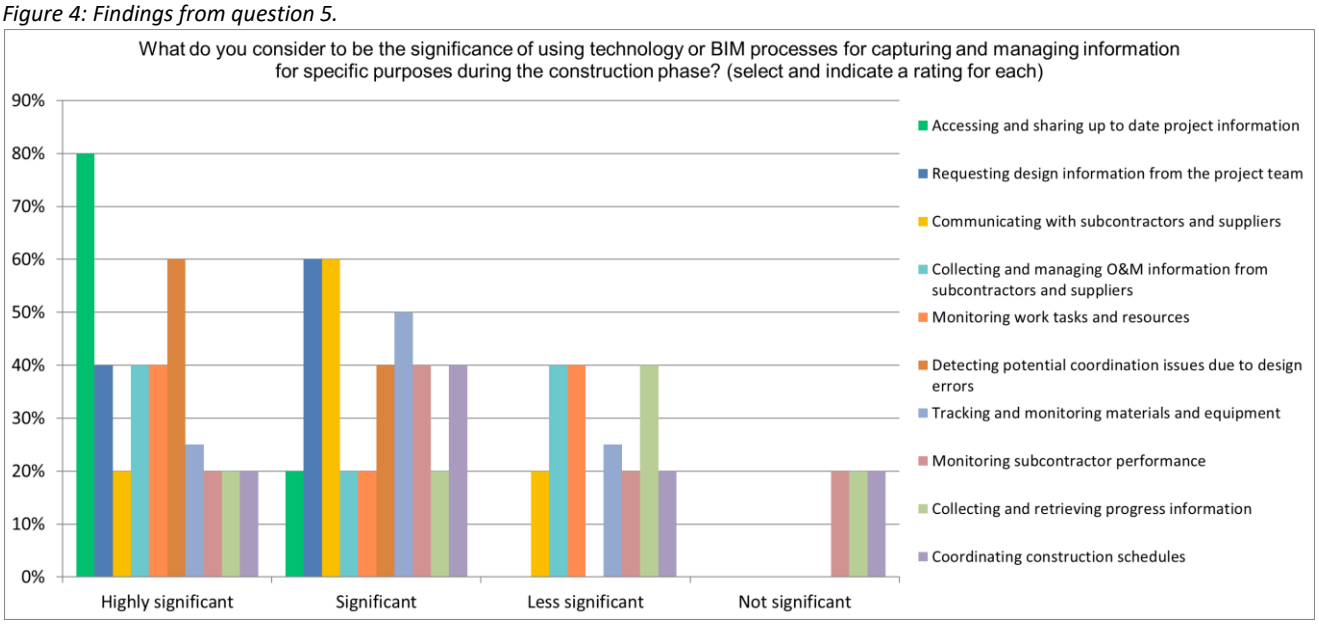


Figure 4: Findings from question 5.



Discussion

The progression of the research from initial BIM implementation strategies in response to Government mandate, through pilot projects to more focused case studies provide a broad range of parameters within a tier 1 contractor's operations to inform that construction projects need to be reviewed from a holistic point of view. Effective information management at all stages is key. A critical review of the current 1192 standards revealed the lack of a standard specific for end of life processes.

Peer reviewed research including (Mursell, 2018) and (Bateson, 2015) supports the view that a holistic look at project lifecycle benefits from early contractor involvement. Having

underpinned key decisions on such matters as buildability and procurement, continued tier 1 contractor's involvement during the construction phase provides the platform for a systematic and seamless capture and recording of good quality information at installation that would become invaluable at end of life processes.

Even when the design stage establishes ways of installation that facilitates deconstruction, if data is not captured and recorded in a structured way at the construction phase, there will be no evidence to validate that the asset, as built, and as represented by the asset information model, AIM, has physically been installed in accordance with the design as specified. A vital link to end of life process will have been lost. Critical importance should be placed on the capture and storing of the installation data, including Construction Operations Building information exchange, COBie, in an accessible and easily retrievable manner for use during the maintenance and ultimately at the deconstruction phase. This study provides initial but significant insight on how a tier 1 contractor's contribution towards information or data capture during the construction phase will become vital during the deconstruction process.

In the survey for the BIM Level 2 case study projects it was revealed that site teams mostly use a combination of hand written notes and some form of technology for site processes. This validates (APS Group Scotland, 2013)'s view that current methods of data collection are not consistent and therefore do not promote strategic thinking. The savings that can be realised from site activities when technology is used, are significant, as illustrated by the results from the pilot projects. For example,

- 57% savings in time required to duplicate handwritten field notes to computer.
- 75% savings on time required to run QA/QC checklists including photographic evidence and signature sign-off and report generation).
- 87% improvement on time in tracking down missing information e.g. for O&M manual sections.

If the survey on the case studies indicates that retrieval of information as "not easy" for all the activities mentioned above, the importance of information management during the construction phase cannot be ignored anymore. There is a valid business case to get site teams to use technology.

CONCLUSION

Literature review confirmed that a specific standard is required to complete the 1192 standards to complete the whole life cycle value. Qualitative questionnaires and in-depth interviews confirmed that BIM and technology are necessary for a tier 1 contractor to manage information better on construction projects. Quantitative results from the pilot projects indicated that technology during the construction phase can provide considerable savings.

Findings from the BIM projects used as case studies show that current methods of data capture during the construction phase are unstructured and do not therefore provide useful information required for end of life processes. Results showed that it was "not easy" to retrieve information at any period after practical completion including during the Defects Period (one year after handover). If this is the prevailing situation it is fair to conclude that key information that may be required at the end of life of built assets will not be easy to find.

This research reveals that whilst work has been undertaken to promote effective project team collaboration through innovative technologies like BIM the decisive piece to close the sustainability loop, is still missing, as the current standards do not address the end of life processes. The research justifies the value of collaborative work beyond the maintenance phase of construction projects. Challenges remain to propose better ways of data capture and information management during the construction phase to facilitate re-use of information.

The study contributes to the missing link in the research area by proposing that the next phase builds a framework of how and what type of information needs to be collected, stored and managed so it can be readily available at the asset disposal stage specifically for deconstruction purposes. Information relating to the remaining useful life of a building component, or how the building component should be deconstructed and prepared and tested for re-use are examples of data that could be captured and managed in BIM models specifically for end of life processes.

The research concludes that only through standardised and regulated site installation approaches can the retrieval and repurposing of the COBie data in the Asset Information Models, AIMs, be extended for appraising the value of physical asset components for reuse at feasibility stages of future projects. This preliminary research provides the basis from which to further develop the BIM 1192 standard to guide a sustainable deconstruction process.

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A WASTEWATER TREATMENT MODELLING STUDY - COMPARING A STANDARD STATIC MBR FOULING MODEL WITH AN INNOVATIVE ROTATIONAL MBR MODEL WITH THE ROTATIONAL FUNCTION SWITCHED OFF

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Abstract

Fouling by activated sludge in membrane bioreactor (MBR) processes for wastewater treatment can be limited using several strategies. Some proprietary MBR systems use novel rotating, flat sheet membranes to assist in fouling limitation. In previous work, an attempt was made to model this rotating fouling process by developing a simulation model based on traditional fouling mechanisms. In order to directly compare the potential benefits of rotational MBR systems, a follow-up study was carried out using the Avanti RPU-185 Flexidisks newly developed static (non-rotating) MBR system. This new process uses the same proprietary membrane arrangement as used in the rotational unit. However, it is configured instead as a static square-shaped unit, in-line with the more traditional submerged flat sheet MBR systems. During this study, the results from operating the static pilot unit were simulated and modelled using a standard fouling model coupled with a viscosity to mixed liquor relationship model. These results were then compared with those obtained from running the rotating MBR model however with rotational switching functions turned off and rotational parameters set to a static mode. This was carried out to determine whether the basic premise of the developed rotational model was empirically sound when compared to a standard MBR flux model. Relatively good agreement was reached between the two types of models, thus vindicating the usage of the rotational MBR model.

INTRODUCTION

Water scarcity is a growing global problem, with rainwater harvesting and wastewater reuse as possible new sources of water being grossly underutilised at the moment (Templeton and Butler 2011). In terms of wastewater reuse, this has become a serious option with the introduction of filtration technologies known as membrane bioreactors (MBRs), in particular non-rotating or static MBRs (SMBRs). Since their emergence, they have experienced an increase in usage (Xing et al. 2000, Fenu et al. 2010). Although these SMBR systems do perform well, they might be supplanted in the future by newly developed rotating MBR (RMBR) systems that potentially have reduced energy consumption and fouling (Bentzen et al. 2012). RMBRs characteristically induce high shear effects on the membrane surface thereby reducing associated fouling whilst minimising energy usage. These systems have been shown to yield high permeate flux in the ultrafiltration (UF) range (Bhattacharjee and Bhattacharya 2005),

whilst the very high shear rate simultaneously yields a good system performance by preventing cake formation and subsequent increased concentration polarisation (Jaffrin et al. 2004, Jørgensen et al. 2014). Unfortunately, a single persistent issue, namely membrane fouling that is characterised by flux decline or trans-membrane pressure (TMP) increase during MBR filtration operation time, which has been be-devilling this field of research for years, came to light along with the increase usage of MBRs (Judd 2006, Drews 2010). Fouling by non-Newtonian fluids such as activated sludge used in MBR systems is a key limiting factor in UF membrane processes.

According to Hermia (1982), during constant pressure UF filtration, three major fouling mechanisms can occur. These are typically known as pore constriction, pore blocking (usually divided into either complete or intermediate) and cake filtration. The aforementioned fouling mechanisms describe the accumulation of particles, solutes, and colloids inside the membrane's pores and on the membrane's surface leading to a reduction in the diameter of open pores (i.e., pore constriction), an obstruction of the pores by particles larger than the membrane's pore size (i.e., pore blockage) and the deposition of layers of particles onto the blocked membrane surface (i.e., cake filtration).

Moreover, depending on the composition of the liquid being filtered and the interactions between the membrane and the bulk liquid, one fouling process may dominate over the other two or all three mechanisms may simultaneously occur throughout the filtration's duration time (Hermia 1982). Many fouling studies have been carried out to date using pilot units in order to determine the best operating conditions of MBR systems, although currently, due to the complexity of the biomass matrix which includes living micro-organisms, no definitive theories on membrane fouling have been established (Yoon 2015).

Different approaches have also been developed for modelling the physical and biological aspects of membrane fouling in a normal non-rotational MBR system. For instance Meng et al. (2005), established a fractal permeation model while Liu et al. (2003), presented an empirical hydrodynamic model. Duclos-Orsello et al. (2006), introduced a fouling model that combined all three classical fouling mechanisms which was later used by Paul (2013) as a starting point for a greatly refined model for a side-stream MBR that incorporated both hydrodynamics and SMP effects.

Because mathematical modelling can be used to simulate flux decline and thus potentially afford a greater understanding of the membrane fouling mechanisms involved, the aims of this study was to:

i. Create a comprehensive fouling model that incorporates hydrodynamic regimes for a standard SMBR using a viscosity to mixed liquor relationship model developed by Yang et al. (2009). Then validate said fouling model using filtration data collected from operating Avanti's square-shaped SMBR.

ii. Compare these results with those obtained from running the Paul and Jones (2015) RMBR model however with rotational switching functions turned off and rotational parameters set to a static mode.

Theoretical Approach

Since the square-shaped SMBR system was operated under constant transmembrane pressure (TMP), both fouling models (static square-shaped and standard) must be evaluated in terms of the varying flux. With this MBR mode of operation, as the filtration process goes on, the flux declines, indicating fouling.

In this research work, three fouling mechanisms are chosen. Let us consider Figure 1a, b and c as the fouling mechanisms that occur during a typical filtration process (e.g. UF) for membranes that have been fouled for the square-shaped SMBR. During the filtration timeline, fouling is observed with respect to the change in TMP (or flux), mixed liquor suspended solids (MLSS) level, or a combination of both.

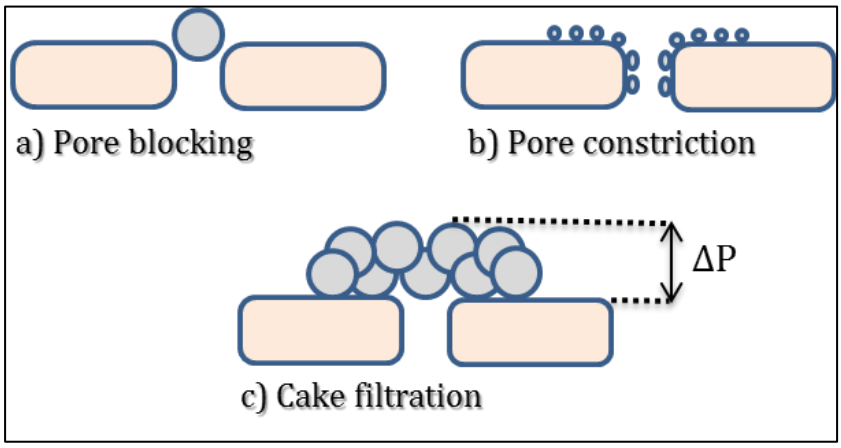

Figure 1. Diagram of the combined fouling mechanisms: Colloids or small particles constrict the pores while larger particles block them, and accumulate to form a cake

Firstly whilst referring to Figure 1a, b and c, it was assumed that the membrane's pores were cylindrical and uniformly distributed throughout the membrane, so that fluid flow could be described by Hagen-Poiseuille flow. Hence, pore constriction occurs through all open pores, and gradually the membrane surface becomes obstructed by aggregates forming a somewhat uneven blocked area. Once the pores are blocked by aggregates, pore constriction is stopped.

Consequently, a cake layer will form over any blocked area. The resistance of this deposit layer is time dependent with regions of greatest resistance delivering the smallest flux. However, in reality the actual membrane fouling process is extremely complex in nature with usually all effects simultaneously occurring. Nevertheless, to simplify the model the above assumptions are made as well as overlooking the effect of frictional forces and temperature (Paul and Jones 2015, Paul and Jones 2016).

Study Specific SMBR Fouling Model

Paul and Jones (2015), developed a comprehensive fouling model for Avanti's RMBR (RPU185 pilot unit). This model included all three classical fouling mechanisms as well as the hydrodynamics including the rotating shear effects (Paul and Jones 2015).

A bespoke SMBR system that utilised Avanti's square-shaped membrane module was then fabricated at our laboratory. Paul and Jones (2016), developed a static fouling model based on this system. To obtain this fouling model, the rotating functions in the RMBR fouling model were switched-off. By removing the rotational switching functions, the fouling model of the RMBR reverts to that of a submerged SMBR system (i.e., square-shaped) that now simply includes the air scouring term as hydrodynamic regime. This is shown through Equation 2.1 which computes the total flow rate through membrane (Paul and Jones 2016), Q_t ($m^3.s^{-1}$);

$$Q_t(t) = \frac{A_{u_0}.J_0}{(1+\beta.Q_0.C_{MLSS}.t)^2}.e^{\left\{\frac{\alpha.J_0}{\beta.Q_0}.\left(\frac{1}{1+\beta.Q_0.C_{MLSS}.t}-1\right)\right\}} + \frac{-PT}{\mu.(R_m.(1+\beta.Q_0.C_{MLSS}.t_b)^2+R_b)}.\int_0^t\left(\frac{A_{u0}.\alpha.C_{MLSS}.J_0}{(1+\beta.Q_0.C_{MLSS}.t_b)^2}.e^{\left\{\frac{\alpha.J_0}{\beta.Q_0}.\left(\frac{1}{1+\beta.Q_0.C_{MLSS}.t_b}-1\right)\right\}}\right)dt_b \quad (2.1)$$

and, Equation 2.2, which includes hydrodynamic factor, air scouring flux, J_{air} ($m.s^{-1}$), to compute the net area effect (Paul and Jones 2016):

$$\frac{dA_b}{dt} = \alpha.J_u.A_u.C_{MLSS} - k_{A_b}.(\alpha_v.J_{air}).\theta_c(t) \quad (2.2)$$

Generic SMBR Fouling Model

Activated sludge in MBR systems is classified as non-Newtonian fluid that can be expressed as a function of MLSS. This was studied in depth by Yang et al. (2009). From their study, viscosity (μ, Pa.s) is proportional to MLSS as seen in Equation 2.3 such that:

$$\mu = 0.0126.(C_{MLSS})^{1.664}.e^{\frac{E}{R_g.(T_{room}+273.15)}} \quad (2.3)$$

During UF, as the membrane becomes fouled and flux gradually decreases, the total available area for permeate will decrease at a uniform rate such that, there exist a time constant t_c (s^{-1}) < 1/t that yields area formulation Equation 2.4. Assuming time constant, t_c (s^{-1}), is proportional to the initial flux (as TMP is constant), the area formula Equation 2.4 can be further expanded such that:

$$A = A_0(1 - t_c.t) = A_0(1 - K_\alpha.Jm_0.t) \quad (2.4)$$

As can be observed from the above equation, it is quite similar to Hermia (1982) area formulation. A Taylor's expansion of order 1 of $\ln(1 - K_\alpha . Jm_o . t)$ at $t = 0$ is $\approx -K_\alpha . Jm_o . t$. This reduces the area formulation to Equation 2.5.

$$A = A_0 . \ln\left(e . (1 - K_\alpha . Jm_o . t)\right) \equiv A_0 . e^{(-K_\alpha . Jm_o . t)} \quad (2.5)$$

Due to caking observed during UF process, the total resistance will increase with the membrane area available for filtration. According to the in-series resistance approach, the total membrane resistance is defined as the summation of the cake's resistance and all other mechanisms' resistances. As such, by including the pore constriction mechanism and constant ϕ, R_{total} (m^{-1}), can be can be computed as seen in Equation 2.6.

$$R_{total} = (R_{in,b} + \varphi . R_b) \quad (2.6)$$

At time t_b (s), once the pore constriction stops, the time at which a pore was first blocked, resistance $R_{in,b}$ can be calculated by Equation 2.7 (Duclos-Orsello et al. 2006),

$$R_{in,b} = R_m(1 + \beta . Q_0 . C_{MLSS} . t_b)^2 \quad (2.7)$$

The resistance of the particles deposit increases with time due to the growth in mass (or thickness) of the cake layer, and with the cake filtration model, resistance, R_b, (m^{-1}) is given by Equation 2.8.

$$\frac{dR_b}{dt} = f' . R' . J . C_{MLSS} \quad (2.8)$$

The flux, J ($m.s^{-1}$), can be calculated from Equation 2.9 using Darcy's law at constant TMP and the in-series resistance approach.

$$J = \frac{TMP}{\mu.(R_{in,b} + \varphi.R_b)} \quad (2.9)$$

Thus, by combining Equations 2.3 to 2.9, the total normalised flow rate through membrane, Q_t ($m^3.s^{-1}$), is expressed in Equation 2.10 as the product of the available area and the flux.

$$Q_t(t) = \frac{TMP}{0.0126.(C_{MLSS})^{1.664}.e^{\frac{E}{R_g.(T_{room}+273.15)}}.(R_m(1+\beta.Q_0.C_{MLSS}.t_b)^2+\varphi.R_b)} . A_0 . e^{(-K_\alpha . Jm_o . t)} \quad (2.10)$$

Where,

R_g is the universal gas constant (R_g = 8.3145 × 10^{-3} kJ.K^{-1}.mol^{-1}), E is the so-called activation energy which according to Yang et al. (2009) is 9.217 (kJ.mol^{-1}) for the viscosity of sludge, T_{room} is the room temperature in °C.

The only prevalent hydrodynamic factor to take into account during operation of a standard submerged SMBR (e.g., bespoke square-shaped SMBR) is the air scouring which is mainly in charge of mitigation cake growth and thus reduce fouling. Additionally, air scouring flux, J_{air} (m.s^{-1}), is a key parameter for the management and prevention of membrane fouling in most submerged MBR systems.

Thus, an additional removal term defined as the flux induced by the air scouring flow effects was added. This supplementary removal term is also in-line with Liang et al. (2006), cake's formulation equation. An analogous reformulation is found in Equation 2.11 but includes the air scouring effects.

$$\frac{dR_b}{dt} = f'.R'.J.C_{MLSS} - g_o.(\alpha_v.J_{air}).\delta'.(R'_c.\theta_c) \qquad (2.11)$$

MATERIALS AND METHODS

This section covers experimental methods as well as the materials used to acquire the filtration data.

Materials

Figure 2 shows the set-up and operation of the square-shaped SMBR rig that was fabricated using a bespoke static square-shaped membrane module (Flexidisks by Avanti Membrane Technology, Walnut, California, USA). This rig generated filtration data that in turn were used to validate and test the SMBR fouling models described in Section 2.

Figure 2. Static square-shaped membrane bioreactor (MBR) system in operation. The square membrane module is located in the larger tank on the right for filtration purposes.

The UF membrane module consisted of 20 static membrane flat sheets. Each membrane sheet in square form was composed of hydrophilic, low fouling polyvinylidene fluoride (PVDF) polymer with the manifold that collected the permeate flow being located in the single shaft. The viscosity of the fluid was measured daily by the aid of rotating viscometers (Rotary-Viscometer ASTM by PCE Instruments UK Ltd, Southampton, UK; and High Shear CAP2000+ by Brookfield Viscometers Ltd, Essex, UK), whilst the MLSS concentration was logged continuously by a MLSS analyser (GE-138 MLSS Suspended Solids Sludge Concentration Meter Analyser Monitor by A. Yite Technology Group, Wanchai, Hong Kong).

Table 1 shows this second unit's membrane dimensioning and a general overview of the operating conditions of the bespoke SMBR system as provided by the manufacturer.

Table 1. Dimensions of membrane module operating conditions of the bespoke SMBR.

Description	Unit	Values
Individual Membrane Width	m	0.24
Individual Membrane Length	m	0.24
Total Membrane area	m^2	1.152
Operating Temperature	°C	~ 5 – 60 °C
Permeate flux	$L.m^2.h^{-1}$	> 30
TSS (Total Suspended Solids)	$g.L^{-1}$	> 8
TMP*	bar	> 3

* = Transmembrane Pressure

Operational Regime of Plant

The SMBR plant was initially seeded with activated sludge supplied by Thames Water, UK, and were semi-batch fed a synthetic wastewater made up using a standard recipe to mimic an influent wastewater source. MLSS concentrations were kept between the range of 6.32 and 7.24 g/L by periodic excess sludge wasting. The influents had an average pH between the range of 7.8 and 8.6, and experiments were carried out at a constant room temperature of 23 °C.

TMP Flux Stepping Experiments

Using standard protocol in-line with Le Clech et al. (2003) and Paul and Jones (2015), TMP stepping was performed so as to procure filtration data from the bespoke SMBR. Although two TMP steps up were carried out for each variation in MLSS concentration, for validation of both models only one TMP step was considered: the high constant TMP of 45 kPa. Since biological activities occurring at this high TMP and MLSS levels are active, the probable irregularities in filtration data would be good to test the validity of both models. TMP steps were carried out at constant TMP of 15 kPa and TMP of 45 kPa.

The corresponding initial flow rates were respectively 1.2 x 10^{-5} m^3/s and 2.5 x 10^{-5} m^3/s. Although data was constantly being logged, for the sake of simplicity and to keep model computation time down to a minimum, only the average data points for every 5 minutes of filtration time were actually used in the simulation study with the total filtration period being two hours. This meant a total of 25 data points were generated for each individual MLSS concentration. After each TMP step testing, a chemical backwash was carried out with 125 mg/L worth of sodium hypochlorite solution and the membrane resistance was calculated to measure the extent of irreversible fouling.

On unit start-up, for the square-shaped SMBR system, the clean membrane resistance was determined to be 4.55 x 10^{11} m^{-1}.

RESULTS AND DISCUSSIONS

The flow regimes during filtration processes of the square-shaped SMBR were laminar which were well within expectations since calculated radial Reynolds number (R_{eNN}) values were much less than 2×10^5.

In the square-shaped SMBR fouling model, parameter α solely contributed to pore blocking, parameter β solely contributed to pore constriction and a combination of parameters $f'.R'$, R_{bo}, g_o and k_{Ab}, all contributed to cake filtration. For the standard SMBR model, parameter β contributed to pore constriction whilst a combination of parameters $f'.R'$, R_{bo} and g_o, all contributed to cake filtration. $K\alpha$ and φ were indicative terms for pore blocking.

The aeration rate for all the data sets for the SMBR system was similar in scale to that of the RMBR system operated under lab scale conditions (i.e., the usual air scouring flow rate of 3.55×10^{-4} m^3/s). Thus, similar constant values for air scouring coefficient, α_v, (i.e. 0.0292), and the resistance distribution factor of cake layer, δ', (i.e. 4.6×10^{-4} m^{-1}) were used during all simulations. So as to ascertain validity of both SMBR models, only the six most important parameters pertaining to the three fouling mechanisms were used for data and curve fitting during simulations.

These were $f'.R'$, α, β, R_{bo}/R_m, g_o and k_{Ab} for the square-shaped SMBR model and $f'.R'$, β, R_{bo}/R_m, g_o, $K\alpha$ and φ for the standard SMBR model. For both fouling models, these best fit simulation values were attained by minimising the sum of squared residuals between the model and the collected experimental data. This was used in conjunction with "Genetic Algorithm" function in the Matlab software package with an initial population large enough for the data set used to converge to the minimal possible error. The simulations were performed for TMP of 45 kPa for MLSS concentration range of 6.32 g/L – 7.24 g/L. The simulations best fits parameters that were obtained are summarised in Table 2.

The obtained best fit values (Table 2) appear fairly sensible since they are in-line with earlier work done (Paul and Jones 2016). In addition, they also present an accurate depiction of dominant fouling mechanisms. However, at this high TMP and MLSS concentration range, point to point simulations of experimental data of both models were quite poor (as seen on Figure 4 and 5). A reason for this largely expected outcome is that sludge rhealogical effects which themselves are volatile will dominate nearly all membrane fouling mechanisms in unpredictable ways especially at high MLSS concentrations with associated high viscosities. This situation is less prevalent for the rotating MBR system, as both air scouring and rotational shear contribute to the reductions in fouling (Paul and Jones 2015, Paul and Jones 2016).

Table 2. Simulations best fit model parameters including hydrodynamic effects.

	Bespoke SMBR model	**Standard SMBR model using Yang et al. (2009) viscosity model**
Optimised parameters	*Data simulated at TMP of 45 kPa and MLSS level range 6.32 g/L – 7.24 g/L*	
f'R' (m/kg)	108.8×10^{11}	106.9×10^{11}
α (m^2/kg)	0.907	–
β (kg)	0.486	0.637
R_{bo}/R_m *(–)*	0.526	0.466
g_o *(–)*	15.36	12.20
k_{Ab} *(–)*	14.23	–
Kα (m^{-1})	–	13.91
φ (–)	–	19.78

As part of the simulation process, curve fitting for the fouling decline of both SMBR systems are outputted by Matlab. They are shown here by Figure 3 and 4.

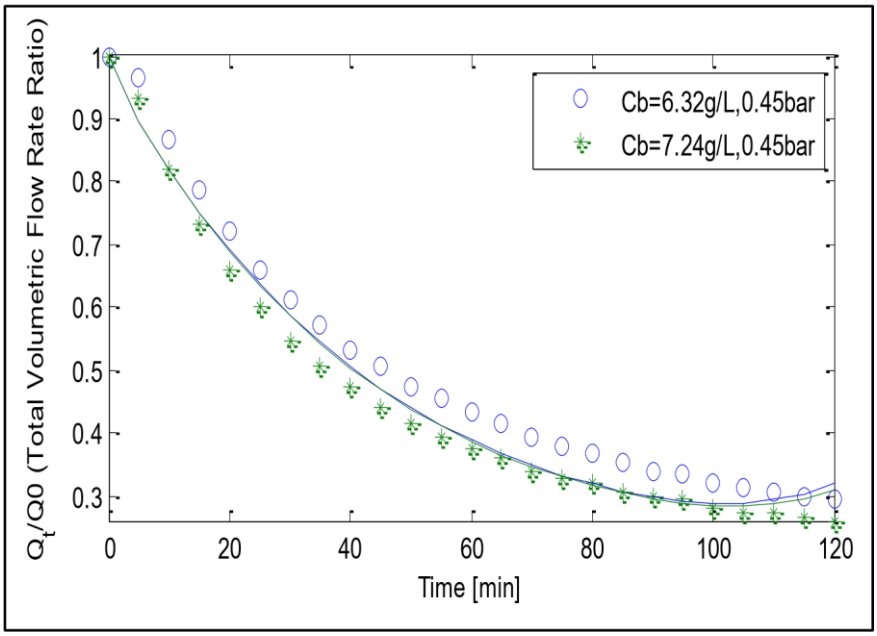

Figure 3. Standard SMBR model: Flux decline for TMP step at constant TMP of 45 kPa for MLSS concentration range 6.32 g/L – 7.24 g/L

Figure 3 depicts the effects of the fouling behaviour of the standard SMBR model, using the normalised volumetric flow rates for MLSS concentrations of 6.32 and 7.24 g/L at a constant TMP of 45 kPa; with the solid lines representing the best fit simulation solutions. The experimental data show that there is massive flux decline. In fact, there is an over 70% drop in flux. At high MLSS level biological activities tend to be active, this means that flux will diminish at a faster rate (i.e., fouling occurring faster).

Therefore, this flux drop which is translated in the simulated fouling curve is well within expected margins (Paul and Jones 2015). Another obvious fact is that the point to point fit of experimental data is very poor. But, the fouling curve's trend is of the right scale and in the right direction to allow an analysis of the fouling behaviour that is occurring in the system. A large $f'.R'$ coupled with R_{b0} being nearly equal to R_m suggests that significant cake layer was formed.

Furthermore, the ratio of φ by $K\alpha$, which indicates to a fair degree the distribution density of blocked pores area (i.e., an indication of pore blocking), is just over twice the size of pore constriction parameter β (as roughly 1.42 is superior to roughly 0.64). This indicates that pore blocking mechanism was predominant during fouling. Consequently, the majority of the fouling was controlled by both pore blocking and cake filtration.

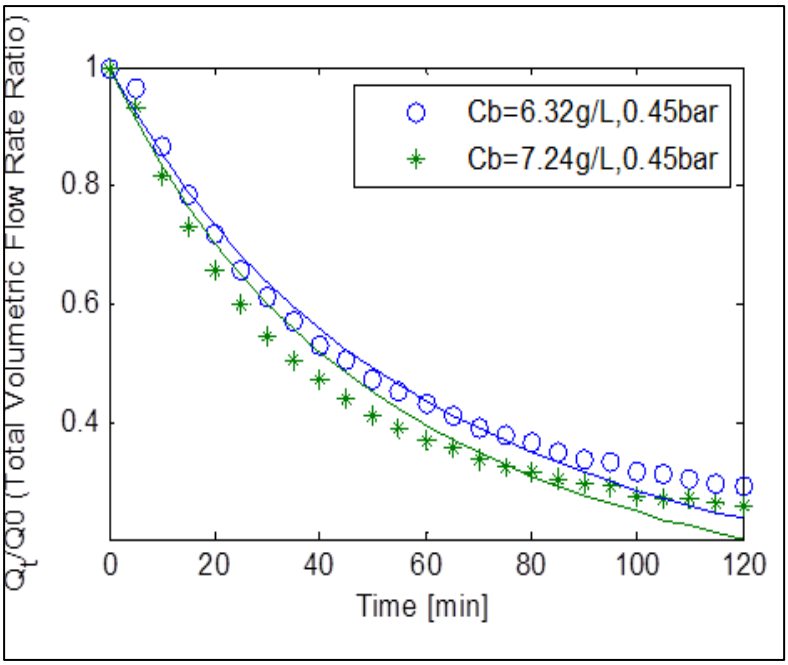

Figure 4. Bespoke SMBR model: Flux decline for TMP step at constant TMP of 45 kPa for MLSS concentration range 6.32 g/L – 7.24 g/L

Figure 4 shows the normalised volumetric flow rate ratios plotted against the filtration time at constant TMP of 45 kPa, for MLSS concentrations of 6.32 and 7.24 g/L for the square-shaped SMBR model; with the solid lines representing the best fit simulation solutions. Data collected show a colossal drop in flux of over 72% for both MLSS levels. This is within expectation based on past studies (Paul and Jones 2016).

Also, as can be seen, the best fit curve at this high TMP is extremely poor (especially after 80 minutes). However, the fouling curve's trend is of the right scale and in the right direction to allow an analysis of the fouling behaviour that is occurring. Superficially, analysis would suggest that fouling may be due to all three fouling mechanisms, but it can be argued that fouling was mainly dominated by cake filtration and pore blocking.

A relatively big $f'.R'$, R_m being nearly equal to R_{b0} coupled with similar sized cake removal factor, g_0, and blocked pore area constant, k_{Ab}, all strongly shows that a big cake layer was formed (see Table 2). However, with the pore blocking parameter, α, being roughly twice as big as the pore constriction parameter, β, it can be inferred that the pore blocking fouling mechanism was also prevalent during fouling. Hence, the bulk of the fouling was dominated by both cake filtration and pore blocking.

In terms of comparison, overall both SMBR fouling models gave a near identical depiction of the fouling mechanisms that occurred during filtration process. Although their point to point experimental data fits were poor, the trend of their simulated fouling curves more than made up for this deficit.

CONCLUSION

In a previous study using a novel RMBR, a fouling model incorporating rotational and hydrodynamics effects was developed using first principles (Paul and Jones 2015). In that study, it was concluded that rotation efficiency in terms of fouling prevention was estimated to be increased by 12%. In a further follow up study (Paul and Jones 2016), a static fouling model was developed based on the RMBR fouling model by switching off its rotating functions. The work showed that a rotating MBR system could increase flux throughput by a significant amount when compared against a similar static system although there are obvious additional capital and operational cost implications.

In this research study, a standard fouling model for a SMBR that included hydrodynamics was developed using the viscosity to mixed liquor relationship model developed by Yang et al. (2009). It was fed filtration data collected at high TMP and MLSS concentration from running the bespoke square-shaped SMBR. Although point to point experimental data fitting was poor, the trend of the simulated curve (i.e. fouling decline) was respectable. This is to be expected for at high MLSS level biological activities vary wildly. When compared with the SMBR model that was obtained by switching off the rotational functions of the RMBR model, the latter has better point to point experimental data fitting but shares similar and respectable fouling curve fitting trend with the former.

Despite the discrepancies in point-to-point data fitting of both SMBR models, their similar fouling decline curve fitting trends suggests that good agreement was reached between experimental and simulated fouling decline (and by extension occurrence of fouling mechanisms). This not only indicates that the basic premise of the developed RMBR model was sound in empirical terms when compared to a standard flux model, but also vindicates the usage of a complex RMBR model. Follow on studies will now compare results from the RMBR system using rotational models developed by other researchers to ascertain the effectiveness of this rotating MBR modelling approach.

Acknowledgments

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Nomenclature

Symbols (Equations)

A, remaining membrane area available for permeate (m^2);
A_0, (total) membrane area (m^2);
A_b, blocked membrane area (m^2);
A_u, unblocked membrane area (m^2);
A_{u0}, initial unblocked area (m^2);
C_b, liquid bulk concentration (g/L);

C_{MLSS}, mixed liquor suspended solids concentration (g/L); f', fraction of foulants contributing to particles deposit growth (−); g_o, cake removal factor (−),
J_0, initial filtrate flux of clean membrane (m s^{-1});
J_{mo}, initial total flux within membrane (m s^{-1}); J_u, unblocked flux (m s^{-1});
k_{Ab}, area constant parameter for blocked pores (−);
K_α, area distribution density (m^{-1});
PT, transmembrane pressure at membrane periphery (Pa);
Q_0, initial volumetric flow rate (m^3 s^{-1});
Q_t, total volumetric flow rate (m^3 s^{-1});
R', unit cake layer thickness per unit mass of fluid filtered (m/kg);
R'_c, specific cake resistance (m^{-2});
R_b, resistance of solids deposit over a region of membrane (m^{-1}); R_{bo}, initial resistance of solids deposit (m^{-1});
$R_{in,b}$, membrane's resistance & resistance from pore constriction (m^{-1});
R_m, clean membrane's resistance (m^{-1}); R_{total}, total membrane resistance (m^{-1});
t, filtration time (s);
t_b, time at which a membrane region was first blocked (s);

Greek Letters α, pore blockage parameter (m^2/kg); α_v, air scouring coefficient (-); β, pore constriction parameter (kg); δ', is the resistance distribution factor of cake layer (m^{-1});
ΔP, cake's transmembrane pressure (Pa); ϑ_c, cake's depth or thickness (m);
μ, viscosity (Pa s); φ, a constant accounting for total amount of cake layers formed (−);

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