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International Sustainable Ecological Engineering Design for Society (SEEDS) Conference 2016

Conference Proceedings

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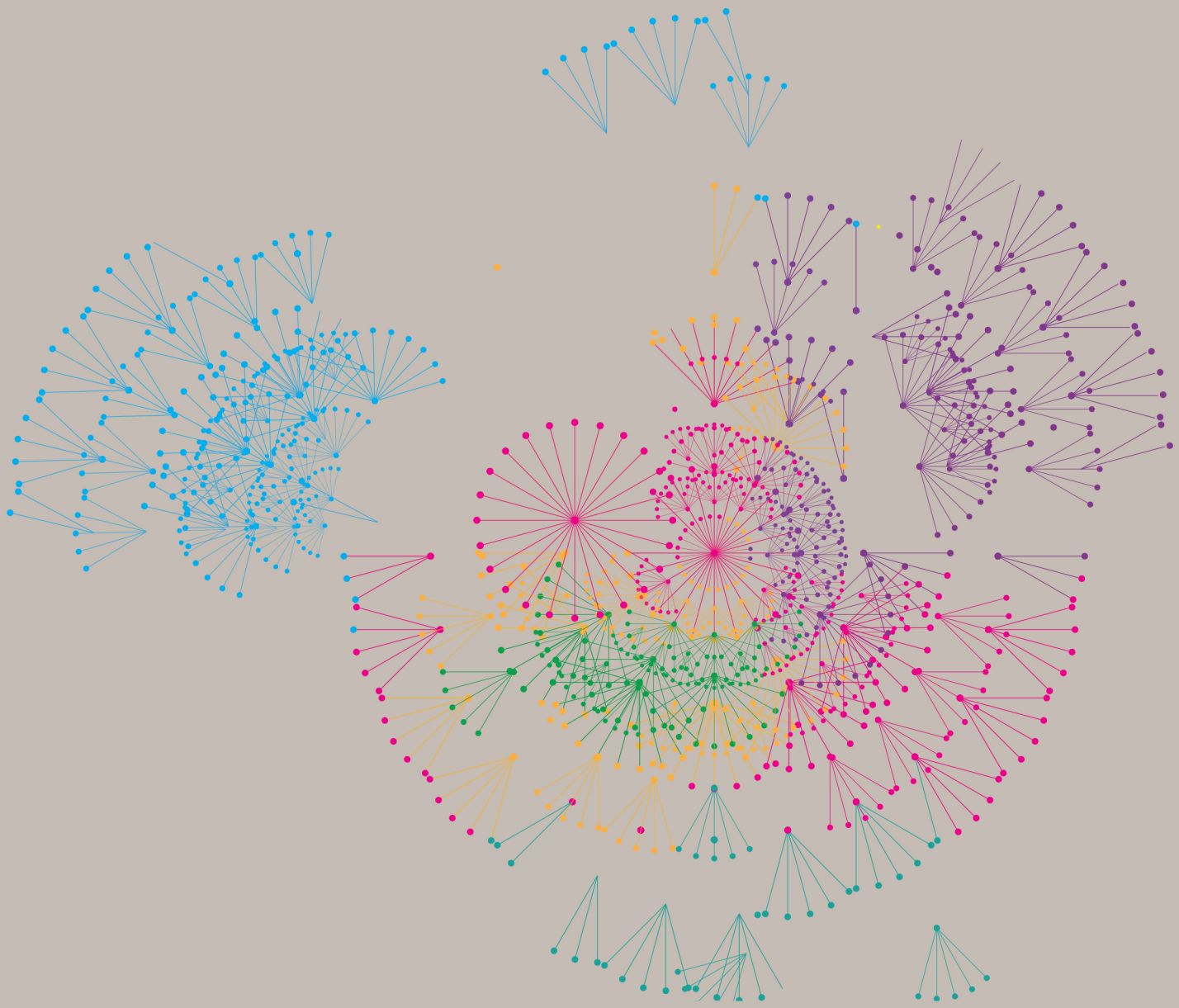

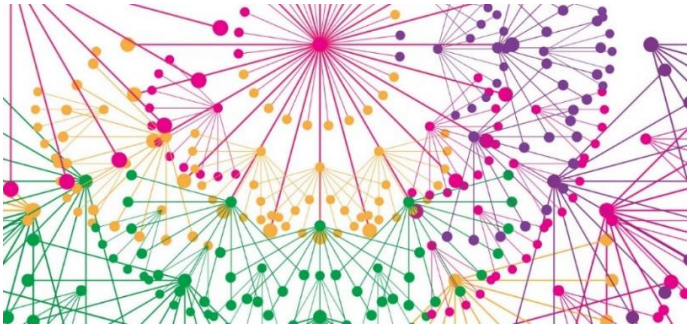

Sustainable Ecological Engineering Design for Society (SEEDS)

Selected Papers from the Second International Conference

Conference Chairs
Professor Mohammad Dastbaz
Professor Chris Gorse

14 & 15 September 2016

Leeds Beckett University

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SELECTED PAPERS FROM THE INTERNATIONAL SEEDS CONFERENCE 2016:

SUSTAINABLE ECOLOGICAL ENGINEERING DESIGN FOR SOCIETY

2016 Conference Theme: Built and Natural Environment: Sustaining a Healthy Ecosystem

As the world population continues to grow, so does the demand placed on the Earth's natural resource. Those in developed countries continue to outstrip the exploitation of world resource whilst at the same time placing pressures on developing countries to be more sustainable. Regardless of the lack of harmonisation all countries need to contribute to preserve a habitable and healthy planet. The built environment and its impact on natural resource poses a considerable threat. With the built environment's demand for natural resources, including energy, materials and water, as well as the waste and emissions produced, the negative impact exerted on the planet is greater than any other industry.

Beyond the green rhetoric, some make a real effort to bring about change towards more sustainable ways of living, working and coexisting, but others continue to ignore the changes that are taking place. Evolutionarily, we are intrinsically bound and reliant on our neighbouring life forms. While it is wrong to assume that the world will always remain the same, the balance of the ecosystem is easily tipped and destruction of living organisms, which have evolved over millennia, can be quickly brought to an end. Securing the health of 'our ecosystem' for as long as is possible is central to our survival. Ensuring the negative impacts of the built environment and human activity are reduced to a more sustainable level is at the heart of the conference. The International SEEDS conference brings together experts from around the world focussing on the changes that are taking place and the benefits or consequences that are being predicted. Emphasis is placed on the health and wellbeing of the users of spaces occupied and enclosed, supported by an understanding of the technical issues and systems that are there to support understanding. Developing knowledge of how buildings and spaces are designed, used and nurtured to obtain the optimal outcome is the focus of discussion. The SEEDS approach draws together the research from wide themes of energy, building performance and physics while placing health, education, 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 reducing negative impact and providing for the health and wellbeing of the society. 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 themes and topics covered by the papers include:

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 quality
Air quality
Education
Planning and sculpturing positive change
Reducing consumption and waste
Sustainability, ethics and responsibility
Occupant behavioural change
Community building and masterplanning
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
Designing edible urban landscapes
Knowledge

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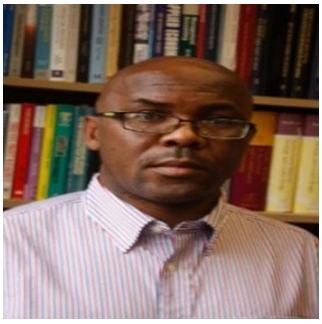

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My key areas of expertise are in the areas of energy performance of buildings and monitoring buildings using sensing technologies. I also have a background of Energy Engineering and I am a Chartered Building Surveyor (MRICS). Both of these roles have involved many retrofit projects of both commercial and domestic buildings and the associated monitoring of their performance.

At the Energy House, we have carried out research for many large multinational companies, on new energy efficient technologies, and also some large scale building physics investigations into subjects such as the co-heating test and whole house heat loss methodologies, and researching the effects of various different forms of insulation.

As a Part Time PhD student my main area of research is in the area of building energy performance monitoring, and the use of sensors in building to validate the effectiveness of energy efficient interventions.

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Since 1999 Prof Laing has led a number of research commissions, including 'Streetscapes' (Scottish Enterprise), 'Greenspace' (ECFP5, Scottish lead) and 'Urban Connections (Aberdeen City Growth). These projects provided techniques for assessing human responses to virtual built environments. In addition, he has recently led research and development projects for the Department of Health and the ESF, as well as participating as a co-investigator on work supported by the ESRC. Professor Laing has extensive experience of research concerning holistic value assessment in the built environment, including studies on design evaluation, the use of computer games technology in design, building conservation and innovative housing. The research has produced over 50 outputs. Recent papers have appeared in leading journals including Environment and Planning B, Design Studies and the Journal of Building Appraisal.

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The SEEDS 2016 Conference Papers that have been published by Springer in a separate book entitled, 'Building Information Modelling, Building Performance, Design and Smart Construction', edited by Mohammad Dastbaz and Chris Gorse are listed in Appendix A.

Building Performance Analytics

A DOMESTIC MONITORING METHODOLOGY TO MEASURE ENERGY CONSUMPTION AND TARGET ENERGY REDUCTION

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Keywords: Energy Monitoring, Retrofitting, Energy Reduction.

ABSTRACT

Energy monitoring is needed in domestic retrofit project to evaluate the performance of energy efficiency technologies in retrofitting projects. Energy consumption must be monitored before and after the technology installation. While energy monitoring technology is widely available and can cover for a range of budgets, energy efficiency retrofit projects are being faced with a hard choice of imposing a high expenditure in monitoring equipment but able to reliably capture a big range of data at short interval or facing a low budget monitoring approach resulting in a reduced amount of data captured, periods of missing data and issues in measuring the benefits of retrofitting efforts.

The aim of this study is to propose a monitoring methodology for domestic properties and compare to other monitoring approaches to measure energy consumption and target energy reduction due to energy efficiency implementations (technology approach) and/or user behavior changes (human approach).

The methodology was developed on the basis of the experiences and feedback captured during two retrofitting projects accounting for the energy reduction of domestic properties after the implementation of air source heat pumps (technology approach) and user behavior strategy.

Three parameters are used to compare and evaluate the proposed monitoring methodology to other monitoring strategies.

Local authorities, social landlords and general energy users can implement this methodology in a low budget approach to be able to measure the results of implement energy efficiency changes to a range of properties and make decisions on the success or changes to be made to their retrofitting strategy.

INTRODUCTION

The world is facing environmental challenges as a consequence of the effect of climate change due to emission of greenhouse gases into the atmosphere, which is mostly driven by the energy generation and CO_2 emissions according to the International Energy Agency (2016). Following the 21st Conference of the Parties (COP21) in Paris and as published in the Adoption of the Paris Agreement (UNFCCC, 2015) it was agreed to hold the increase of average global temperature to below 2 ˚C. According to the Intergovernmental Panel on Climate Change (Lucon et al., 2014), in 2010 the building sector accounted for 32% of total global final energy use.

The United Kingdom has agreed under law to reduce CO_2 emission levels by 20% across the EU by 2020 and 80% by 2050 (HM Government, 2009). To achieve these targets, efficiency and low carbon technologies are being deployed in new built and retrofitting projects and energy monitoring must be part of the strategy as it provides the collection and analysis of energy performance assumptions in the properties (Swan & Brown, 2013).

Energy monitoring is needed in domestic retrofit project to evaluate the performance of energy efficiency technologies in retrofitting projects. Energy consumption must be monitored before and after the technology installation. According to a review on smart metering by Johnson (2010), smart metering can be classified in three groups:

- Group 1: Provision of real time energy consumption and rough costing, e.g. Current Cost - Envi.
- Group 2: Building on the capabilities of Group 1 and providing the options to be alerted according to parameters set by the user, e.g. Tendril Vision.
- Group 3: The most advanced providing detail energy consumption analysis at appliance level, e.g. GEO - Trio.

While energy monitoring technology is widely available in non-domestic projects and can cover for a range of budgets, domestic energy efficiency retrofit projects are being faced with a hard choice of imposing a high expenditure in monitoring equipment (Group 3) with the benefit of reliably capturing a big range of data at small intervals or using a low budget monitoring approach (Group 1) resulting in a reduced amount of data captured, periods of missing data and issues to measure the benefits of retrofitting efforts.

The aim of this study is to propose a monitoring methodology for domestic properties and compare to other monitoring approaches (Group 1 and 3) to measure energy consumption and target energy reduction due to energy efficiency implementations (technology approach) and/or user behavior changes (human approach).

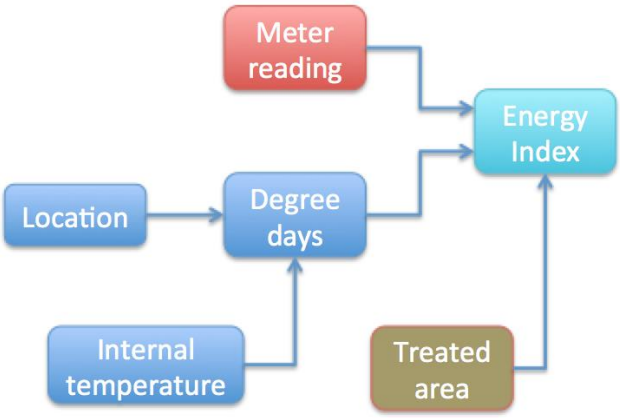
RESEARCH METHODS

The methodology was developed on the basis of the experiences and feedback captured during two retrofitting projects accounting for the energy reduction of domestic properties after the implementation of air source heat pumps (technology approach) and user behavior strategy.

The proposed monitoring methodology has been initially described and discussed by Jimenez-Bescos (2015) and it is based on the following inputs to generate an energy index:

- Energy consumption in kWh taking from direct meter readings. As it provides the most accurate measure of actual energy consumption (Swan & Brown, 2013).

- Treated area in m^2.
- Internal temperature in degree centigrade.
- Outdoor conditions depending on location, taking as degree days for the particular location (CIBSE, 2006) and Krarti, 2012) and has been used to forecast energy demand (Hong, 2013).



To provide a comparison of the proposed methodology to Groups 1 and 3, three parameters are used according to the following descriptions:

Figure 1. Normalised energy index methodology

- **Cost:** This parameter refers to the capital, installation and operation cost of the monitoring equipment. Value 1= low cost and value 5 = high cost.
- **Reliability:** This parameter refers to the quality of data collected and the probability of data lost. Value 1= little reliable and value 5 = very reliable.
- **User Input:** Referring to the data manipulation by the user to collate, evaluate and compare data. Value 1= little input and value 5 = high input.

RESEARCH RESULTS

Every energy monitoring strategy has been evaluated in accordance to the three parameters presented in the methodology (Cost, Reliability and User Input) and presented in Figure 2 as a radar graph to compare to each other.

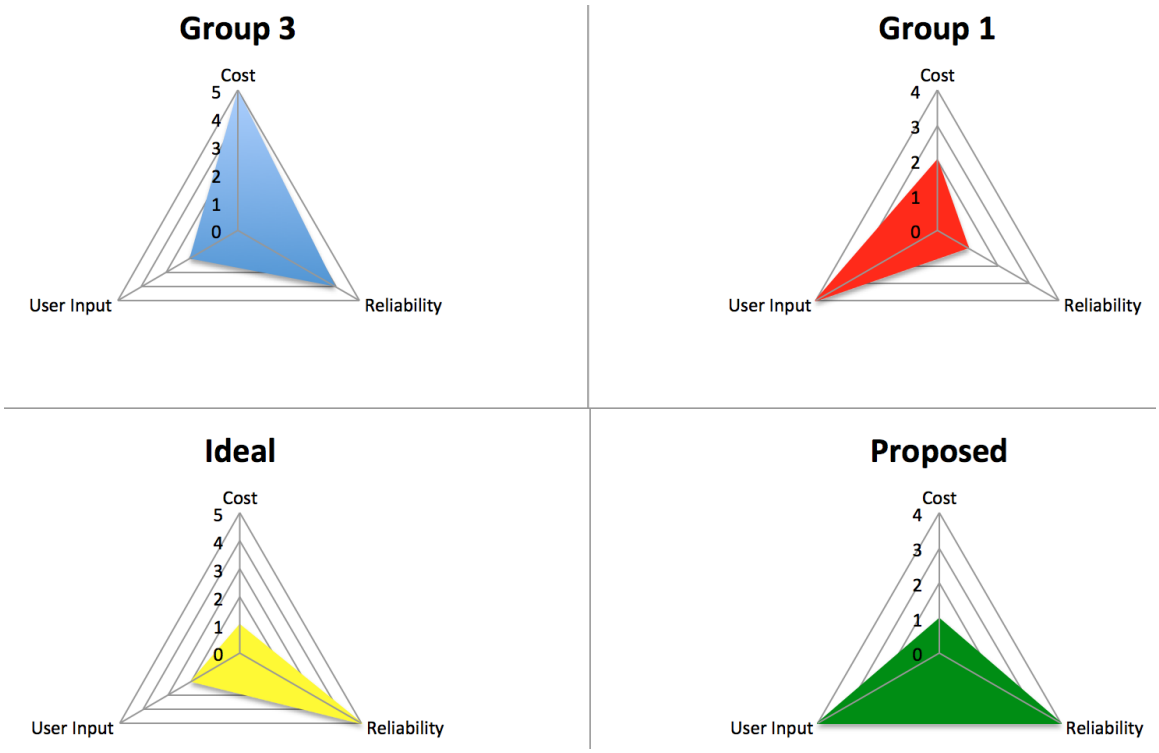


Figure 2. Analysis of monitoring strategies according to Cost, Reliability and User Input.

Group 3: Refers to the commercially available energy monitoring equipment adapted from the industrial to the domestic market. The equipment required a high expenditure but providing a reliable data collection at small intervals and with very limited data loss. The user input is normally low with data visualisation capabilities and remote data collection.

Group 1: Low budget monitoring strategy as used in many retrofitting projects due to budget constraints. The strategy provides a low cost equipment approach but as experienced by the author, data loss and reliability is proportional to the cost (Jimenez-Bescos, 2016). Low budget approaches require a high level of user input to collect, analyse and visualise data.

Ideal: The ideal monitoring strategy, which would satisfy all the stakeholders in any retrofitting project, would have a low cost, with a high reliability (no data loss and very good data collection) and minimal user input. This monitoring strategy is evaluated as the target to achieve.

Proposed: The proposed monitoring methodology has a low cost as very little equipment is needed apart from temperature sensors. Reliability is high due to the high user input in collecting meter readings and temperature data. The only issues on reliability will be due to human error.

Figure 3 shows the four monitoring methodologies in a radar graph to visualise the comparison between methodologies for discussion.

Figure 3. Comparison of monitoring methodologies.

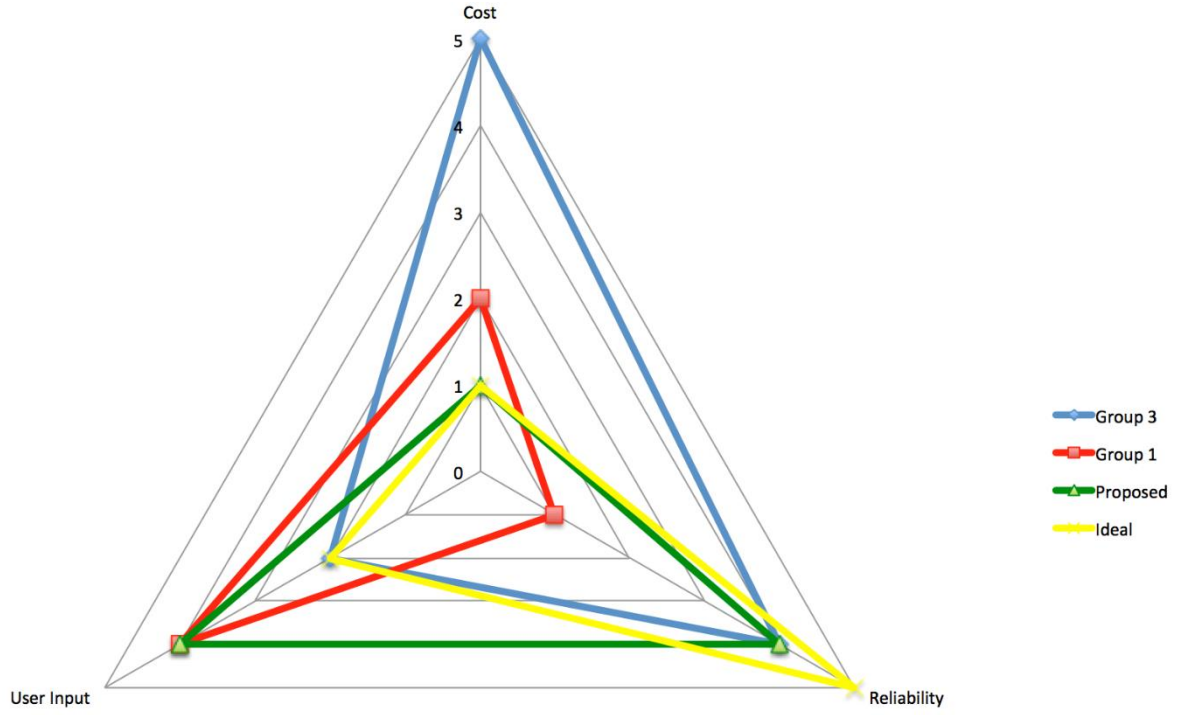


Figure 4. Application of Energy Index methodology to meter reading data.

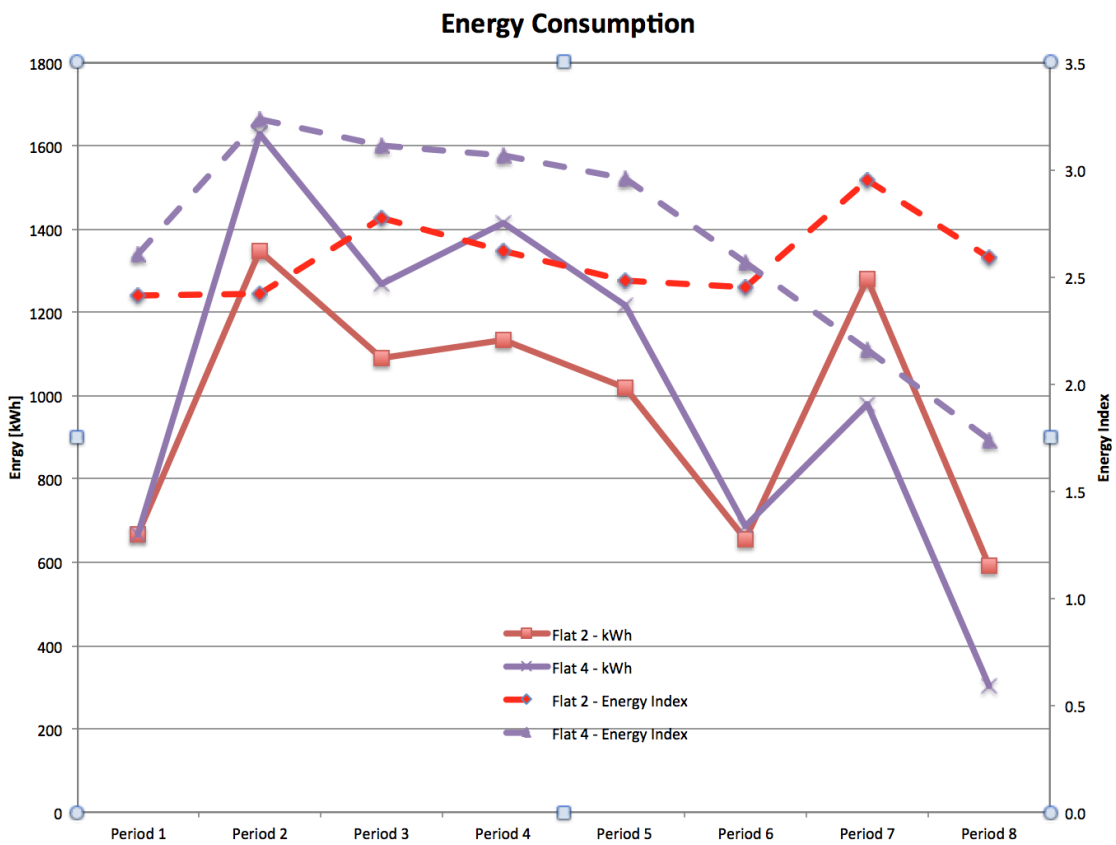


Figure 4 shows the application of the proposed energy index methodology to the meter reading collected in two flats.

DISCUSSION

As described in the results section, the ideal monitoring methodology should be employed in all retrofitting projects to satisfy all the requirements by stakeholders.

From the point of view of achieving great reliability on the data, a high expenditure must be taken forward but this approach is not suitable in most projects due to the budget restrictions among projects and monitoring being probably one of the last things to be taken into consideration in terms of budgeting. This is the approach taken by Group 3 monitoring methodology.

Due to budget restriction, the approach taken by Group 1 is normally adopted to try to achieve the Ideal monitoring methodology. Although the cost is highly reduced, as experience by the author, the cost reduction is affecting as well the reliability of the data collected, in terms of data loss and quality of the data (Jimenez-Bescos, 2016). Furthermore, the user input is increased, as the user must be able to collect, analyse and prepare the data visualisations.

The proposed monitoring methodology is as well trying to move from Group 1 methodology to match the Ideal strategy. This is achieve by a low budget approach based on meter reading and temperature data, making the strategy very reliable as equipment errors is very much minimised. The drawback for this high reliability and low cost is a high reliance on user input for collection, analysis and presentation of results.

As it can be found in Jimenez-Bescos (2015), the main benefit of the proposed monitoring methodology is not the low cost but the possibility to measure energy consumption and evaluate energy reduction in retrofitting projects implementing a technology approach and/or a changing user behaviour strategy. As it can be seen in Figure 4, flat 2 and flat 4 were mostly reducing their energy consumption as per meter reading (kWh) until period 7, when both flats seem to have a high increase of energy. If the proposed energy index methodology is applied to the data for flat 2 and flat 4, dotted lines in Figure 4, it can be observed the energy reductions are actually more progressive and there is a smaller increase of energy for flat 2. Period 7 coincided with a cold weather spell and it was expected a higher energy consumption.

Using the proposed monitoring methodology presented in this paper, energy reduction can be compared across different properties and at different locations to help the decision making process of effectiveness of the implemented solutions, while keeping a low budget approach.

CONCLUSION

Local authorities, social landlords and general energy users can implement this methodology in a low budget approach to be able to measure the results of implement energy efficiency changes to a range of properties and make decisions on the success or changes to be made to their retrofitting strategy.

ACKNOWLEDGEMENT

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Building Performance and Evaluation

APPLICATION OF AUGMENTED REALITY TO RECYCLING AUTOCLAVE EMULATION

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Keywords: Augmented Reality, Autoclave, Recycling, Programmable Logic Control.

ABSTRACT

Augmented Reality (AR) has been around for many years, for example, Sutherland (1968) developed the first Heads Up Display and Mann (1980), is regarded as the godfather of AR. This field of research has been used in many areas, from construction to medical applications. Other areas including art and media are widely accepted. There are many challenges however for AR to be considered in other industries. The acceptance of AR as a viable tool to promote, educate and investigate new technologies is still a barrier, Kipper (2013).

This research investigates how AR may be used to promote the benefits of using Autoclaves to recycle refuse, rather than use scarce landfill. The benefits of using this new technology includes the use of methane, produced from processing the refuse to heat the Autoclave, has the further benefit of the reduction of the Green House Gas effect (GHG). Other benefits include separating the plastic for recycling and sterilising organic matter to be then used in landfill.

The main aim was to develop a fully interactive model that would help educate potential users as to the process cycle; the function of each element of the machine and to promote the fact that safety was essential to its operation. From this the potential to train operatives is also a key consideration. Other benefits include online marketing of this technology, using interactive 3D web browsers.

This paper describes how the model was created in 3D and the functionality of the autoclave was developed using a scripting language. The control of the system model was created to match the real control system i.e. marrying real control to the emulation.

INTRODUCTION

The UK buries more than 18.8 million tonnes of household waste per year; this is two million tonnes more than any other EU country, Grice (2010).

This article goes on to state that “57 million tonnes of rubbish, including industrial waste, are being disposed in landfill sites each year” (par 3), the UK will run out of capacity by 2018. The total level of GHG from landfill sites in the UK was 22.6 MtCO2e of GHG, of which 20.6 MtCO2e is methane was produced in the UK, DoECC (2015). Methane is one of the more potent greenhouse gases and contributed 28% towards GHG production because of this potency,

EU directive states that landfill usage must reduce to 35 per cent of 1995 levels by 2020.

One solution pioneered and manufactured by Group Rhodes is a recycling autoclave, shown in Figure 1. This machine has the ability to sterilise waste material after it has had glass and metal removed, before it is fed into a 65,000 tonnes per annum anaerobic digestion (AD) plant, where it will be converted into biogas for renewable energy generation. The energy generated will be used both to power the plant and for export to the grid. The company estimates that it will generate sufficient energy to power approximately 3000 homes. At the Wakefield facility, less than 10 per cent of the waste received will end up in landfill. It will process up to 230,000 tonnes of waste a year, helping to increase the West Yorkshire local authority’s recycling rate from 40 per cent to a minimum of 52 per cent.

The facility will process up to 230,000 tonnes per annum of municipal solid waste (MSW), which the company said will help to increase the local authority's landfill diversion rate towards 90%.

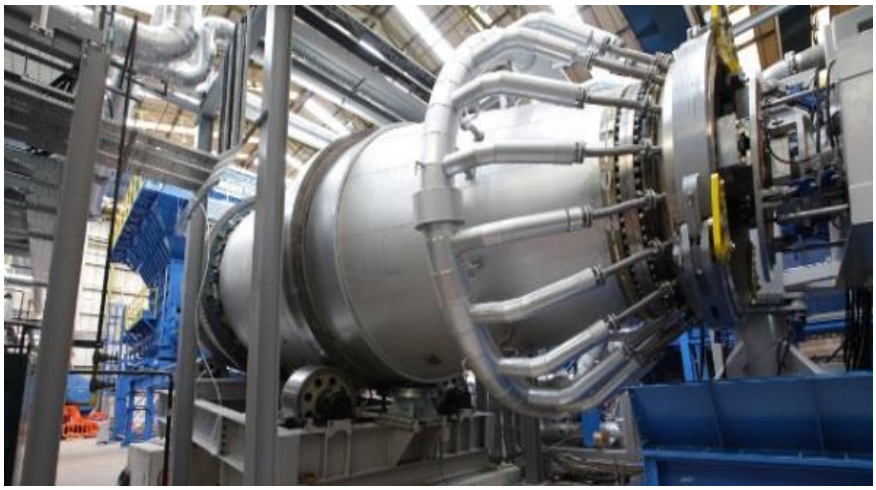

Figure 1. Group Rhodes autoclave recycling system

RESEARCH REVIEW AND METHODOLOGY

The complexity of the Autoclave and its control system needs careful consideration by many people involved in marketing, purchase, management and operation. One of the recent ways of getting inside the workings and operation of this type of equipment is Augmented Reality (AR).

Augmented Reality

Virtual reality is the term used to describe a three-dimensional, computer-generated environment, which can be explored and interacted with by a person. That person becomes part of this virtual environment or is immersed within this environment and whilst there, is able to manipulate objects or perform a series of actions.
Augmented reality on the other hand can be considered as a type of virtual reality. The main aim is to create an environment in a computer that composites together the real world as seen by the user and a computer generated scene, the aim being the end user is unable to see the "join" between what is real and what is augmented.
According to McKalin (2015),
"*With AR, users continue to be in touch with the real world while interacting with virtual objects around them. With VR, the user is isolated from the real world while immersed in a world that is completely fabricated."(par 7).*

Examples of AR within heavy industry

A hydraulic excavator AR simulator (H.E.A.R.S), for operator training was developed by Akyeampong J et al, (2012). This system was required to train staff in the safe operation of heavy equipment required in construction and manufacturing. The author goes on to state that the traditional way to carry this out is usually by offsite and onsite training on the real thing, which is both costly and dangerous. This is supported by Mujber T.S, (2012) who describes AR within manufacturing applications as "allowing the whole design team to work together in the virtual environments". He goes on to show how the number of real prototypes is reduced through the evaluation of virtual ones. Other benefits include the understanding of plans and to support interdisciplinary discussions. Enabling unskilled users to understand and participate in the planning process.

METHODOLOGY

The process for creating an AR version of the Autoclave is described below:

Geometry and Textures

All 3D geometry was modeled from photographs using 3D studio Max, from the real Autoclave shown in Figure 1, it is noted that too high a level of detail requires a high level of processing power, thus resulting in slow viewing transformations, animations and interactions. High levels of detail can be mapped on to surfaces using textures developed from real images of objects. These textures have a bump or normal map to enable surface finishes to be part of the photorealism required.

Animation

The animation of each element of the autoclave sequence was created within 3D Studio Max using key frame animation. The linear translation of the Hooper mechanism as it fed the autoclave and the rotational movement of the doors as they opened and closed. The spinning of the drum was coordinated with the roller and gear drive mechanism as well. Figure 2, showing the Autoclave with both doors closed after the filling operation.

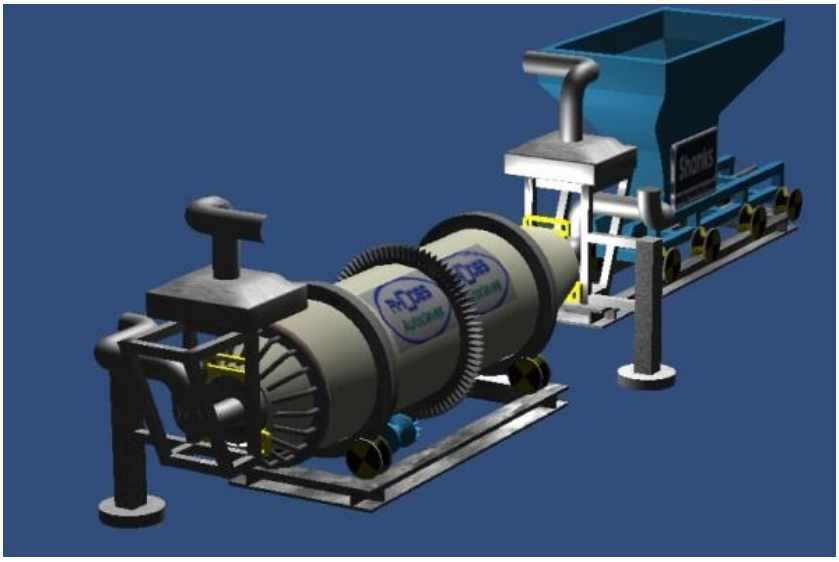

Figure 2. Doors closed after filling operation

Interaction

The interactivity of the AV part was created using the Unity3D game engine and C≠ scripting. The different elements are described below:

Camera

This was a global camera that allowed the user to navigate around the AV Autoclave using the mouse to pan and arc rotate. The zoom settings allowed the clipping plane to be reduced, which gave the effect of slicing through the geometry, allowing for a more thorough investigation of the construction of the autoclave. Figure 3 shows the camera zoom slicing through the barrel of the autoclave, thus revealing the drive mechanism and roller supports.

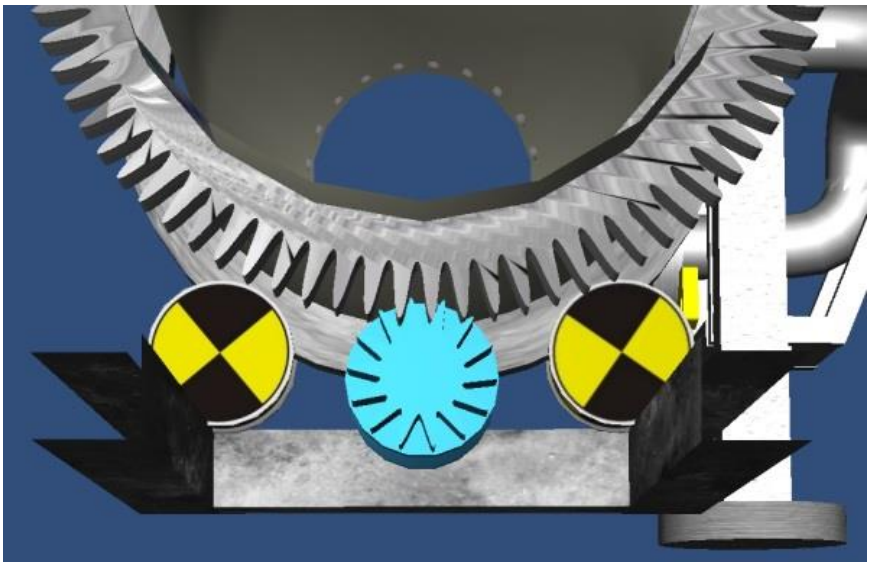

Figure 3. Example of slice using clipping plane within main camera

Collision Objects

Each element of the Autoclave simulation was given a boundary box that enabled the proximity of another object or mouse pointer to interact with the object.

The script for each object was triggered by the proximity of the mouse arrow picking the object in 3D space.

Augmented Information

Infobubbles containing textual information about a particular part of the machine, with an additional high resolution image of the real. Figure 4 shows the pop up augmented information after the 3D objects of the input door; output door and hopper have been picked in 3D space.

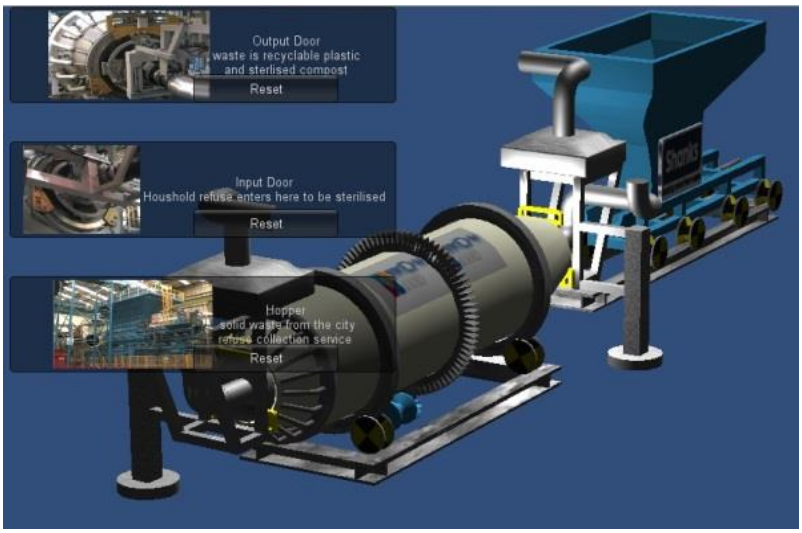

Figure 4. Infobubbles

Programmable Logic Control (PLC) Object

In order to emulate the control of the real Autoclave, Wilkinson (1994) each virtual object must have its own control. For example inputs and outputs of the real world are monitored and activated by a real controller and can be realised within a controller object. Each object can trigger an animation via global signal variables. For example the door closing after the hopper has safely fed the drum with refuse can be activated via a door close global variable signal. In this respect the safety of the real system can be tested for a variety of scenarios. Figure 5 shows how a PLC object within Unity will be able to control the system via global signal variables.

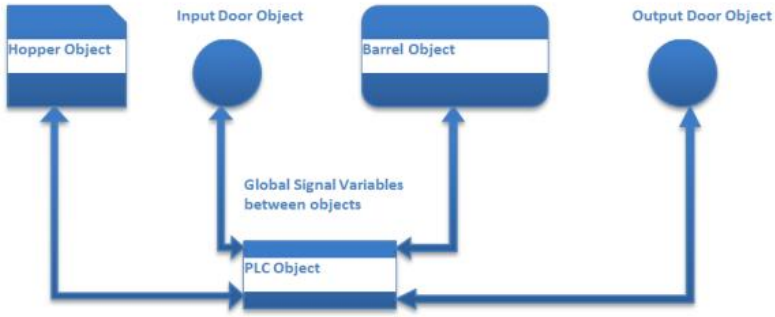

Figure 5. PLC Object

Camera Matching and Tracking

Additional scripting via a Vuforia plugin incorporates edge detection that will enable the virtual Autoclave to be placed within a real location using a Webcam. This can be regarded as a marketing tool that will help customers visualize the machine within its operating environment. This will enable investigation of issues such as operator safety, maintenance clearance, and proximity to other objects for safety reasons.

Testing

The virtual machine was demonstrated at a company event and the feedback from the design team and other engineers was sought. The virtual environment was well received by the demonstration group, though there was agreement that there is potential to bring the emulation closer to reality by expanding functionality. For example the machine should have more physics applied that demonstrates how the internal helical mechanism separates the component parts of the refuse. The machine is on a slope that allows this screw feed mechanism to ensure refuse is transferred from the input door to towards the output door as the drum rotates under pressure. This can be achieved by physicalizing virtual objects within the barrel of the virtual machine.

CONCLUSIONS

Whether its Augmented Reality or Virtual Environments this type of immersive experience can play a vital role in promoting ideas for new technology, especially in the engineering, manufacturing and installation industry. Regarding safety, industry should not sit back and feel complacent, immersive technology can play a significant part in educating operators with an added bonus of creating informative immersive experiences that marketing can use to ensure its customers are fully informed of their products. This research is currently at a prototype stage but offers enormous opportunities for future work.

Acknowledgment

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INVESTIGATING MARKET DEMAND AND SUPPLY OF CONSTRUCTION INDUSTRY WASTE AS A LUCRATIVE OUTLET FOR INTEGRATING INFORMAL SECTOR RECYCLING/SCAVENGING IN PORT HARCOURT METROPOLIS

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Keywords: Integration, Recycling, Scavenging, Waste.

ABSTRACT

The concept of waste minimization by reclamation and recycling is not new. However, it requires thorough integration into the waste management practices of the construction industry in the fast paced and expanding urban setting of Port Harcourt metropolis. The study investigates waste generation on construction and demolition sites in Port Harcourt, their market demand and recyclable potential, as a viable source of income for the informal sector, integral to establishing an inclusive waste management system. Primary data was obtained through the administration of structured questionnaires to construction companies and private developers, interviews with buyers of recyclables, and site visits. The literature and fieldwork reveals that there is a market demand in Port Harcourt for recycled construction waste such as for filling of pot holes on roads, aluminium sheets for smelting into low-grade cooking utensils, oxygenated wood to produce charcoal and firewood for road side sales of roasted food and construction of temporary wooden structures (Bacha) for low income earners. The response pattern also reveals that wastes are generated mostly for cement/concrete, broken blocks, timber and metals. This represents a potentially steady stream of sourcing for reclaimable and recyclable by-products, against the backdrop of the high proportion of construction of new buildings. Furthermore, the findings reveal that, there is no systematic medium of removal of construction wastes from their source, which often occur in new developing upper class neighbourhoods, where such wastes are carted away unsorted to open dumps or dumped in drains along roadways to low income neighbourhoods where the market demand is. Recognising the health and safety implications of scavenging at dumpsites, this study proposes the systematic integration of organized scavenging as a lucrative outlet for construction waste utilization in Port Harcourt, specifically targeted at direct sourcing and separation of materials generated on construction sites by certified scavengers.

INTRODUCTION

Port Harcourt, located in the Southern Nigeria, is one of the fastest growing cities in the country, with a population in excess of one million, based on the 2006 national census (Obinna, et al., 2010b). Port Harcourt is the industrial capital of the hydro-carbon industry and is central to the Nigerian economy. Construction activities are thus on the increase, particularly in newly developing neighbourhoods sprouting up around the periphery of the city centre (Gibb, 2009). It is generally acknowledged that some degree of waste materials is inevitable at building sites, and that measures should be put in place for adequate management of unavoidable waste generated in the course of executing construction works. However, the literature shows that construction wastes in Port Harcourt are largely unmanaged, and constitute a major environmental issue with refuse heaps a common sight on major roads (Wokekoro, 2007; Konya et al., 2013).

The study by Wokekoro (2007) based on interviews with staff of the Rivers State Environmental Sanitation Agency (RSESA), responsible for solid waste management in Port Harcourt, revealed that vast quantities of Construction and Demolition (CD) waste are dumped in open drains causing flooding, or on the road way, constituting a nuisance and health hazard to passers-by and the neighbourhood. Konya et al. (2013) characterized the types of waste disposed at dumpsites at various locations in Port Harcourt Metropolis, based on direct waste sorting and interviews with scavengers. The study showed that CD waste such as concrete, bricks, roofing and insulation materials, metals, plastics, soil, pipes, steel and wood are unsorted, and co-mingled with other municipal solid waste in the dumpsites visited. Weekly refuse collection from the dumpsites along roads is handled by contractors, who dispose of the unsorted waste to final designated sites, typically swamps or burrow pits, located at Whimpey, Abuloma, Elelenwo, and Igwuruta. No formal recycling practise is carried out on the waste by the collectors. Manual sorting and recycling of the mixed waste at dumpsites, and from waste collector carts is however mostly carried out by the informal sector, typically referred to as scavengers. According to Olufayo et al. (2007:142):

> *These young men and women usually enter the dumpsites during the early part of the day moving around looking for used items such as bottles, aluminium sheets, steel, electronics, plastic products, cloths, copper wires and any useful materials. They also keep note of the time and days the trucks offload at the sites. They wait for them and as soon as the trucks arrive, they swarm around the vehicles, looking for any useful materials to pick. Most times, they couldn't afford to wait for the trucks and therefore, jump inside as the vehicles slow down to offload. Once the truck stops, they pounce on the dirt and start picking any useful materials they can lay their hands on.*

Official economic evaluation in other developing countries, such as Jordan show that a drastic reduction in landfill management cost of 79.5%, in savings occur, with the integration of the informal recyclers in waste management (Aljaradin et al., 2015). Official statistics in Lahore, Pakistan revealed a current annual income generating capacity of $4.5 million from the activities of the informal sector, with potential for this to increase to $8.8 million, if informal recycling practices are integrated into the main stream of formal waste management framework. (Medina, 2000). In Nigeria, official statistics on the economic value and contribution of scavengers is sadly lacking, as they are not formally recognised, and are mostly socially stigmatised by wider society (Oguntoyinbo, 2012).

Critique of Informal Recycling Practises in Nigeria

Although scavenging has been recognized as an effective way for managing waste, leading to reduction in the cost of formal waste management systems in developing countries, there are several who oppose this practise. At the core of this opposition to widespread scavenging are the social and public health arguments. Many in the Nigerian society are strongly opposed to the activities of scavengers, leading to wide spread social stigmatisation with the pubic regarding the behaviour of scavengers as appalling and a social nuisance (Oguntoyinbo, 2012). Whereas the government and other public bodies fervently oppose the recognition of scavenging, due to concerns about the implied health risks associated with the activity, leading several authors (Olufayo et al., 2007; Oguntoyinbo, 2012; Aljaradin et al., 2015) to acknowledge that while scavengers see the sorting of the recyclable portion of waste as a source of income and livelihood, public perception and social stigmatisation has fuelled a repressive atmosphere for their activities.

Social stigmatisation has been highly publicised in the media, with many journalists highlighting the social risk scavengers face in Nigeria, espousing that many scavenge out of necessity as a result of societal failure, ultimately they are scavenging for survival. One of the scavengers interviewed revealed that: *'The business is very risky and full of challenges. I only go into the trade so as to make ends meet. Most times, people have accused us of stealing as we walk around looking for items to pick…"* Thisday (2016) A typical response from one of the traders around dumpsites where the scavengers operate was that:

> *Although, they have their reasons, I can't imagine humans picking from wastes deposited by other people. It looks odd. Even we traders that are trading here are highly disturbed because of the odour and smell oozing out from there. It is really risky". The menace became so disturbing that the State Waste Management Authority dragged five scavengers to court where they were remanded in prison custody for illegal entry into the refuse dump site.* Thisday (2016).

These arguments put forward in the Nigerian press, have led academics such as Oguntoyinbo (2012) to call on society to change its view. Rather than socially stigmatising and treating these informal recyclers, who are only guilty of seeking an alternative means of surviving the harsh economic realities of the jobless in Nigeria, society should accept scavenging as a sustainable solution to waste management in Nigeria. This will allow the practice of scavenging or informal recycling to be formally integrated into society, thus improving working conditions. In other words, Oguntoyinbo (ibid) is espousing that scavengers should be seen as an integral part of an inclusive waste management plan whilst presenting Nigeria with a viable option for achieving sustainability in the absence of alternatives.

Returning to the public health argument, Cointreau (2006) and Wachukwu *et al.* (2010) both noted the unsanitary waste collection methods deployed by scavengers, who were described as 'germ infested', and representing a huge health risk to the general populace of Nigeria. Wachukwu *et al*. (2010) investigated the health profile and impact of the activities of scavengers in Port Harcourt, based on experimental microbial counts of infectious pathogens in the blood samples of about 80 scavengers. The study revealed that scavengers carry significantly higher levels of the pathogens present in waste. These pathogens are typically responsible for degradation, such as Staphylococcus Aureus, E. coli and Salmonella sp, with significantly lower level of heamoglobin blood counts. Wachukwu *et al.* (2010) thus concluded that scavengers are carriers of pathogens that are the

primary cause of *inter alia*: food poisoning, urinary tract infections, and typhoid fever. With the latter being identified as a deadly malaise that can be easily spread through the population through contact with scavengers. Scavengers, in the authors' opinion, thus represent a societal health risk and menace that needs to be curbed. The World Bank report by Cointreau (2006) expressed concern that waste pickers rarely use protective equipment and resort to hand sorting contaminated waste, leading to infected cuts and wounds. Oguntoyinbo (2012) recognised that this occupational hazard induced by their working conditions, makes informal recycling incompatible with modern waste management practises, which follow regulatory procedure and require advanced technologically driven methods. Nzeadibe (2009) opined that '*It is true that informal recyclers have the expertise to identify wastes with potential value; however, their unhygienic methods of operation remove the potential to achieve relatively high recycling rates and quality of materials'.*

Oguntoyinbo (2012) however argued that the lack of access to appropriate equipment, limited formal education, training and organisation essentially fosters unhygienic methods of waste sorting and recycling. It was further stated that the health risk that scavengers face has attracted scant constructive policy initiative, unlike the high level of negative social attention. It was regrettably noted that the primary focus of scavengers on daily survival, had left them oblivious to the health risks associated with their working conditions. Oguntoyinbo (2012) further argued that the primary factors driving the activities of the scavengers in Nigeria are the combination of high unemployment rates, high demand for recyclables, poor solid waste management, and high levels of poverty. Leading Oguntoyinbo to assert that official recognition and targeted support with the aim of improving working conditions, mitigating health risks and increasing the social acceptance of scavengers must therefore be considered fundamental to meeting the tripodal millennium development goals of 'poverty alleviation, job creation and environmental sustainability'.

The literature debate on the activities of the informal sector recyclers thus centres on the health and social implications of their practices. Yet it is also noted that there an evident gap in the literature related to the economic viability of scavenging in relation to job creation. This would be essential if the argument, supporting the need for their integration into the mainstream of formally recognised outlets of waste management in Port Harcourt, is to break through into the main political discourse. This argument is further sustained by both Agunwamba (2003) and Nzeadibe (2009) whose works provide important insights into the demographic characteristics of scavengers. Indeed, these studies revealed a mix of young, middle aged, married and unmarried scavengers, with a predominance of males who fully depended on income from this source. However, the analysis also illustrated the viability of their trade, suggesting their earnings are higher than the minimum wage in Nigeria. This shows that informal recycling can also have wider economic benefits. Indeed, interviews with scavengers at a dumpsite conducted by Agunwamba (2003) illustrated the entrepreneurial abilities exhibited by many scavengers with one stating: *'Let me tell you, everything you see here is money. But you see, we prefer any aluminium materials because it costs more money and it is easy to sell more than other materials. Sometimes I make big money, sometimes I make small money like N1, 000 a day'.* Whilst another respondent espoused that he only dealt with polymer products in form of plastic materials due to the return he could achieve, *'I focus more on very strong plastic materials because we have people who buy them up as soon as we bring them. I make more than N800 from polymer products everyday'.* A view strongly reinforced by Oguntoyinbo (2012) who opined that scavengers exhibit high level business acumen: expert knowledge of the types of waste to collect and sort, and the ability to find market outlets for recovered goods which provide cheap secondary raw materials for small scale industries, despite their limited education. These insights lend further

credence to the economic viability of informal sector recycling, which according to Nzeadibe (2009) provides 40% and 48% raw materials to artisans and small-scale industries respectively.

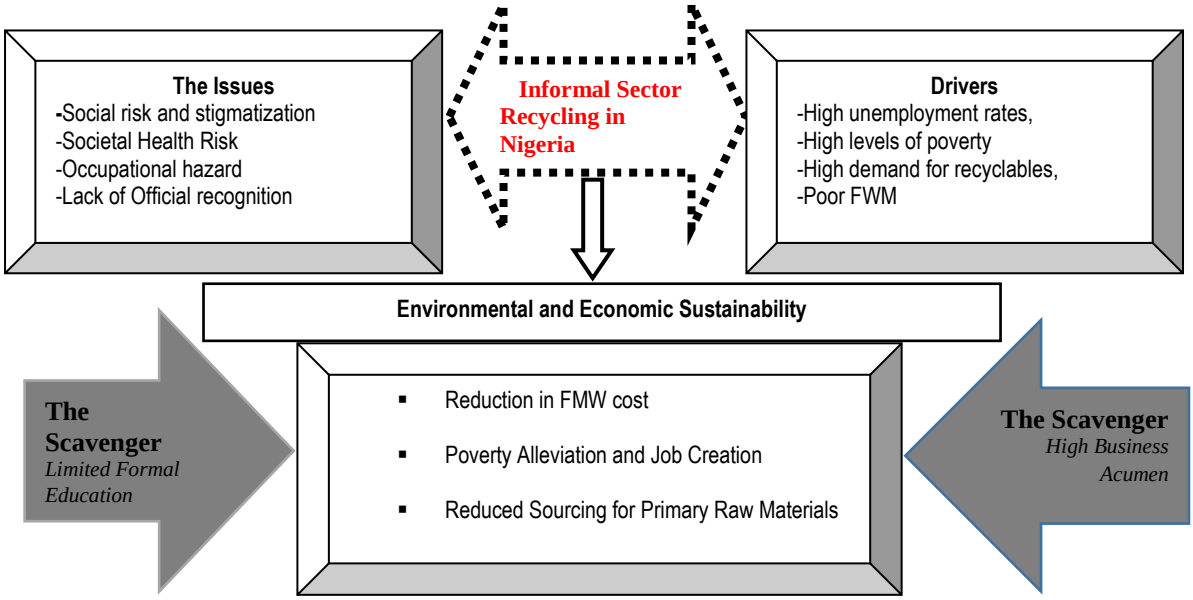

Figure 1: Theoretical Framework (The Reality of Informal Sector Recycling in Nigeria)

The literature review has articulated a multiplicity of issues related to the informal recycling of waste in Nigeria. Despite the social segregation of scavengers, along with very legitimate public health concerns, the literature review has also revealed the economic and sustainable benefits the practice could deliver. With many scavengers exhibiting strong entrepreneurial skills and the ability to generate significant economic returns, this shows that they are able to sustain themselves financially, despite their limited education and high transactional costs. From the literature, the theoretical framework illustrated in figure 1 has been developed. Against the backdrop of this theoretical framework, and considering the high proportion building construction and demolition activities on going in Port Harcourt metropolis, this study investigates the demand and supply of CD waste as a lucrative outlet for the integration of organised scavenging in the construction sector.

RESEARCH DESIGN AND METHODOLOGY

The study utilizes a combination of primary and secondary data to analyze the economic and environmental benefits of informal waste management systems in Port Harcourt. Secondary data, used in this study is based on a combination of archival records from Port Harcourt, and relevant grey literature available in the local area. Exploratory analysis of documents sourced from the Planning Authority was carried out to allow the researchers to understand the development dynamics relating to demolition and building construction trends in the Port Harcourt region. This is because although building related construction and demolition debris are commonly grouped as a single type of material, they represent two different streams of construction industry waste. Construction waste, as used in this study, refers to waste originating from site activities, usually generated as a result of cutting a material down to size for installation or purchasing or mixing material in excess of what is needed. It further includes all surplus excavated soils from construction (Hao et al. 2007). Demolition waste on the other hand refers to the rubble generated from obliteration of part of or a whole built

structure. Literature was also reviewed for information on the uses to which various forms of CD waste can be put, and how it has been used in Port Harcourt.

Following this exploratory phase of data collection, primary data was collected from the identified centres of concentrated construction and demolition activities, using a combination of both a questionnaire to elicit details relating to supply of CD waste. To aid analysis, a final round of qualitative data was collected using semi-structured interviews with six buyers who deal with recyclables supplied by scavengers, allowing the researcher to evaluate market demand for recyclable construction waste. Existing practices in relation to waste generation and disposal were investigated using the questionnaire instrument referred to earlier. The questionnaire was administrated during planned site visits undertaken between June and July 2014. The population sampled for the questionnaires included construction companies, private developers and land owners whose properties had been demolished. The sample size and details of distribution are as follows:

Table 1 Questionnaire Sampling Details

Construction Firm /private developer	No administered	No returned
J. Cappar Construction Company	10	7
Lubrick Construction Company	10	6
Monier Construction Company	10	9
Emmamed Construction Company	10	7
Homan Construction Company	10	7
Master Construction Company	10	8
Renier Construction Company	10	5
Zerock Construction Company	10	5
Private developers	10	8
Property Owners (Demolitions)	10	8
Total	100	70

The questionnaires were designed to elicit data related to the two key themes identified from the literature review, namely (1) waste material generation, disposal and the extent of separation; (2) awareness of the need for recycling and the role of scavengers. As a result, data was collected relating to site waste handling methods, relative quantities and streams of waste generated, level of awareness of the recyclable potential of CD waste, and the activities of scavengers in the area. It is however important to recognize the limitations of the approach adopted. The study does not provide information on the specific quantity of CD waste generated, which may be tenable, with the use of direct observation of the activities of scavengers at dumpsites or from the examination of the waste streams produced at various construction sites, over specific periods. Questions were limited to the relative trend in CD waste generation, and thus cannot serve as a feasibility study on the specific income generating capacity of scavenging in Port Harcourt.

DATA PRESENTATION AND DISCUSSION

Archival Data: Physical Development Pattern in Port Harcourt

Analysis of secondary data revealed that official data on the quantity of CD waste generated in Port Harcourt is not known. However, the documents showed that there are several newly developing residential areas where construction activities are concentrated on the fringes of Port Harcourt metropolis: Artillery area; Woji Area; Iriebe; Igbo-Etche; Akpajo/Eleme area and the Choba/Mkpoba axis. The construction activities mostly consist of: prototype housing estates built by construction

companies for cooperatives, commercial or residential accommodation built by small scale speculative developers who purchase local land, build houses and sell or rent them; and large scale estate developers on long term leases/ capital agreements with native land-owners. These new layouts, mostly upper class neighbourhoods designed as self-sufficient luxurious estates/villas, detached, or semi-detached houses, and mostly occupied by the high-income groups, constitute the beehive of concentrated construction activities.
Demolition activities are less evident in these new layouts, but in older middle class neighbourhoods, where the value of the land has exceeded the building structures erected on them. Typically, these include areas such as Rumuola, Old GRA, Old town areas and D-Line. Also as a result of population increase in these old layouts, the existing roads are insufficient to cater for the increased volume of vehicular traffic triggered by development. Some of these roads were constructed without drainage systems leading to flooding during the rains. Some of the housing was built across storm water flow paths, which further increased flood risk. The development control agency in an attempt to resolve the physical planning deficiency are currently expanding roads, leading to an increase in the volume of demolition of buildings on the right of way. Some of the buildings have thus had to be fully or partly demolished and restructured. Data on the size and specification of buildings demolished, and the volumes of demolition waste produced in specific projects was however unavailable from the compensation files analysed.

Questionnaire Data

- *Waste Supply - Waste Material Generation, Disposal and Extent of Separation*

Figure 2 shows the response pattern to the question of the most wasteful material occurrence. As shown above, 27.14% of the respondents indicate that waste occur from topsoil and excavations. This is followed by rubble from cement/concrete, as well as brick and blocks.

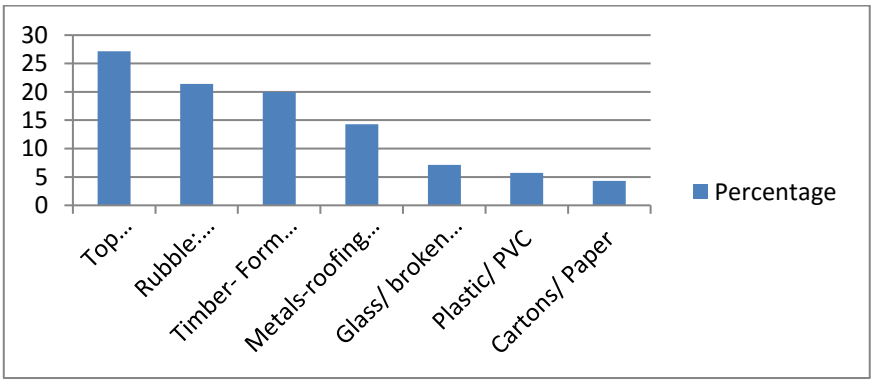

Figure 2: Most Generated Recyclable Waste

Waste timber, metals and glass also had a high percentage of respondents affirming their relatively high level of generation. Material waste from plastics and cartons represented the least generated waste. Table 2 shows the methods of disposal of CD waste, showing that an approximately equal percentage of wastes are carted away to burrow pits or receptacles, as are dumped openly, in drains or along roadways.

Table 2: Percentage Distribution of Existing Methods of Waste Disposal

S/No	Description	Percentage
A	Carting away to burrow pits18	21.43%
B	Open dumping	24.30%
C	Dumping in drains/roadway	24.80%
D	Dumping in receptacles	29.50%

The wastes generated are also largely unsorted as shown in Table 3. A very low percentage of the respondents undertook any form of waste separation at source.14.28% of the respondents separated construction waste for reuse, while the majority (62.56%) responded that they do not undertake any form of waste separation.

Table 3: Extent of Construction Waste Separation and Recycling

	Responses	Percentage
A	Very large extent (all recyclable waste sorted	6.1
B	Large extent (Some recyclable waste sorted)	7.14
C	Low extent (Only re-usable waste sorted)	14.28
E	Not at all	62.56

This finding corroborates the assertions of Wokekoro (2007) who identified that CD waste is not routinely separated before disposal. This is then co-mingled with other municipal waste at dumpsites. There is therefore an identifiable need to encourage sorting of mixed construction waste and reuse and recycling of construction waste before disposal.

- *Awareness of the Environmental Advantages of Recycling and the Role of Scavengers*

Table 3 illustrates that approximately two-thirds of respondents are enlightened about recycling as an environmentally sustainable means of construction waste management. The remaining 32.9% expressed a lack of awareness of the environmental advantages of recycling construction waste.

Table 3: Enlightenment of Recycling as an Environmentally Friendly Outlet for Waste

Description	No of respondent	Percentage
Yes	47	67.1
No	18	32,9

Table 4 indicates that only 17.14% of respondent are highly aware about scavengers as an outlet for recycling construction waste, 28.6% of the respondents indicated that they had a relatively good level of awareness about scavengers as an outlet for recycling construction waste.

Table 4: Level of Awareness about Scavengers as a Possible Outlet for Recycling of CD waste

Description		No. of Respondents	Percentage
High awareness		12	17.14
Good awareness		20	28.6
Average		17	24.28
Non –Awareness		21	30

24.28% of the respondents expressed that their knowledge was average while the highest number of respondents admitted that their knowledge of the subject was not good. This investigation shows that on average the level of awareness about scavengers as an outlet for recycling construction waste is low amongst construction practitioners in Port Harcourt.

Table 5 Activities of Scavengers in the Neighbourhood

S/No	Description	Percentage
I	Scavengers (regular)	24
Ii	Scavengers (irregular)	32
Iii	Scavengers (non-existent	40

Table 5 displays evidence showing trends of scavenging practice deployed in these areas of high construction and demolition activities in Port Harcourt. 40% of respondents affirmed that the activities of scavengers were not evident in their areas. This suggests that scavenging of CD waste as a means of waste recycling in the upper class neighbourhoods in Port Harcourt, even in locations where they operate, is mostly carried out on an irregular basis. It is thus evident that the recycling rate of waste generated on construction sites and from demolitions in these areas is low, mainly due to the suboptimal activities of scavengers.

Discussion: Market Demand and Recyclable Potential of CD Waste

The fieldwork, based on the analysis of questionnaire results, has shown that vast quantities of construction waste in Port Harcourt end up in dumps and landfills despite their reusable and recyclable potential. This section of analysis further discusses and assesses market demand for the top 5 most produced CD waste based on the local literature findings and interviews with buyers of recyclables.

Excavated Top Soils

Excavated soil and rock are usually disposed of at landfills. There is a need to evaluate the potential for increasing the use of excavated soil and rock as construction material. Many excavated materials from construction works in Port Harcourt that would otherwise go to landfill could be used for landscaping schemes on site, for example, valuable materials such as top soil are normally directed to landfill. As topsoil is essential to horticulture, the introduction of topsoil sales to horticulturists for example would provide an effective way of using surplus over site excavated material. This in turn could relieve the local shortage of topsoil material in Port Harcourt. Also red mud used for filling on sites is typically dug from burrow pits, and supplied at a cost of N15,000 per tipper load (20 tonnes). However re-use of excavated soil and rock on other projects would increase landfill avoidance costs for constructors, as Nigeria currently does not have the same landfill taxes as the UK. This could be a lucrative outlet for scavengers to identify such waste soil, via a coordinated effort with suppliers of fill material, who can source excavated soils from sites located by scavengers.

Rubble: Concrete, Bricks and Block

The market size for the use of reclaimed and recycled concrete in Port Harcourt is large and there are opportunities to increase use of reclaimed aggregate. In Port Harcourt, such waste has also proved to be an excellent source of aggregates for filling potholes on roads, where a tipper of hard core and rubbles is sold from N45,000, upwards. Concrete has considerable potential to incorporate reclaimed materials such as aggregate. Concrete and concrete products from demolition or general

construction waste can also be reclaimed in a number of applications in the construction industry. Table 6 shows some applications of debris from concrete and concrete products.

Table 6: Applications of Debris from Concrete and Concrete Products.

Types of debris	General Bulk fill	Base/fill	Road construction	Aggregate for concrete
a. crushed demolition mixed products	Suitable	Usually suitable	Not usually suitable	Not suitable
b. clean Grade mixed products	Suitable	Usually suitable	Suitable in some cases (sub-base only)	Suitable in some cases

(Source: Mujedu et al., 2014)

There is significant potential in building and civil engineering works for reclaimed material to be used in brickwork and block work. At present in Port Harcourt, various constraints mean that such use is very low and should be encouraged and developed. Brick can be recovered separately during the demolition process. Second hand brick may be particularly attractive for aesthetic purposes like facing work etc. Demolition stock needs to be tested carefully to determine its suitability for use (unless a record of brick quality is provided). Crushed Waste Sand Crete Block (CWSB) aggregate can be used as fine aggregate in concrete production and can effectively replace the conventional fine aggregate, sand, in concrete by 50% in medium strength concrete of 30N/mm2 target strength (Bashir et al., 2013). Scavengers can thus source for broken blocks in sufficient quantities for sale to block manufacturers. A guarantee of homogenous materials supply is however a prerequisite stipulated as project specification.

Timber

Due to a limited number of wood processing industries, timber (used and new) is mostly marketed as plank wood (Aiyeloja *et al*., 2013). In Port Harcourt, timber is obtained from two major timber markets: Illabuchi and Marine Base. Based on feasibility analysis carried out by Aiyeloja (2013) at these two markets, the average monthly net incomes from new and used wood sales are N184,239.00 and N70,355. Good quality used wood was described as being in high demand due to the lower price, typically less than half the price for new sawn wood planks. However, used wood was lamented by the marketers as always being in short supply. Aiyeloja's (2013) findings therefore suggest that the sale of reclaimed wood has the potential to be reasonably profitable in Port Harcourt, with a real market in place. Given Port Harcourt generates more than 0.55 million tonnes of timber waste from demolition and construction every year (Isirimah, 2002), reuse of this timber could make a very strong contribution to a more sustainable waste management approach. With appropriate attention by designers and builders, reuse and recycling of timber could be further enhanced.

The buyers interviewed as part of this research identified the potential for a strong market in Port Harcourt for timber reclaimed from demolition sites for conservation and heritage applications, in refurbishing old buildings, and for use in new buildings. Applications to be considered include floorboards, rafters, door and window frames. Secondly reclaimed timber would be in particularly higher demand in lower class neighbourhoods, where it can be used for the construction of wooden structures called 'Bacha', and for firewood and charcoal for roadside cooking and roasting. Thirdly reclaimed timber is also sourced and used for temporary works such as scaffolds, formwork and

earthwork support. Finally, timber from demolition sites is also prized as a source of material for the manufacture of furniture in Port Harcourt.

Metals

With the complete collapse of the iron mining industry, steel manufacturers and rolling companies in Port Harcourt have resorted to the use of waste scrap metal and aluminium products as cheaper alternatives. Scrap metals such as copper and aluminium, in sufficient quantities, are in very high demand. The buyers interviewed for this study revealed that they have scrap yards were they assemble the metal from the group of scavengers who supply them. They have ready buyers from the steel industry so on delivery and assembly of the scrap metal, scavengers are paid 70% of the total sale value of the materials they collect. During the interviews, it was explained that 1 tonne of metal was bought at between N35,000 to 40000; so one trailer of metal would be worth between N350,000 and 400,000. Similarly, one tonne of aluminium would be worth N130,000; and a full trailer of Aluminium would be worth a staggering N1,300,000. Figure 2 shows a trailer of scrap metal being offloaded.

Figure 2: A Trailer of Scrap Metal being offloaded

Most of the metal content of demolition and construction waste will be sold in Port Harcourt, due to its high value. Scrap metal recovered from demolition works in Port Harcourt is usually damaged in the process, making them available only for recycling. Typically, debris such as aluminium roof trimmings are sold by scavengers of metal products for recycling. Other forms of scrap metal from the construction industry typically includes: corrugated iron sheets locally known as zinc; scrap beams or rods; nails; binding wires; and metal trimmings from installation of roofing sheets. Locating these sources of scrap metals, by scavengers, will make a further valuable contribution to the more sustainable management of construction and demolition waste streams.

Glass and Broken tiles

The fieldwork shows that broken ceramic tiles have market demand for use as decorative pieces in concrete slabs. They are usually bought in a mix of different colours for both floor slabs and decorative finishes to fencing and concrete columns within the building. The use of broken glass as aggregate in concrete mixes is also popular. Weihua *et al.* (2000) suggested the use of crushed waste glass as an aggregate in concrete has several advantages, in terms of strength. Experiments evaluating the suitability of broken tiles as an aggregate for concrete by Mujedu (2014) suggested the use of broken tiles as coarse aggregates in the manufacture of lightly reinforced concrete would produce a viable sustainable concrete.

Discussion: Integrating Informal Recycling of CD Waste in Port Harcourt

The study has revealed there are presently no formal waste recycling practices in the Nigerian construction industry. Furthermore, the industry practitioners exhibited low levels of awareness of the environmental advantages of recycling CD waste. CD waste is thus largely unsorted and comingled with other municipal solid waste at the point of disposal, which typically means it is simply dumped along roadsides or taken to dedicated landfill sites. The findings reinforce Wokekoro's (2007) assertions related to the poor management of CD waste in Port Harcourt. Indeed, this study further reinforces the notable difference in CD waste management practises between the developed and developing world identified by Wokekoro (2007). Typically reference was made tothe Dutch approach whereby the disposal of re-usable CD waste was banned, with only certified demolition firms permitted to dispose of non-recyclables at landfills, and tax imposed on the extraction of primary aggregates, encouraging use of secondary aggregate (Wokekoro, 2007). Also in the UK, landfill tax was introduced to encourage recycling. where. It is recognised that recycling should be second only to waste reduction, and as such public enlightenment programmes are needed to raise awareness on the need for waste reduction prior to recycling. In the absence of such formal policies and institutional arrangements to reduce CD waste generation in the Port Harcourt metropolis, scavengers present a viable alternative as an immediate first step towards achieving the goal of waste minimization and environmental sustainability.

The fieldwork shows that there are currently several newly developing residential areas where construction activities are concentrated on the fringes of Port Harcourt metropolis, and also areas of high demolition and repair activities, which represent a steady stream for scavengers to source for CD waste. However, the study revealed only a low percentage of the generated CD waste is recycled in Port Harcourt by scavengers. The data also identified that scavenging is taking place on an irregular basis, with no predictability or reliability. Which from the viewpoint of the construction and demolition teams makes recycling difficult, as waste must be regularly removed from the site. These findings suggest the current recycling rates of CD waste by scavengers in Port Harcourt is sub-optimal. Yet the study also revealed the potential socio-economic benefits increases in scavenging could have for those experiencing severe hardship in terms of poverty reduction, job creation, improved wellbeing and environmental sustainability. Clearly integrating scavenging as a form of organised informal recycling initiative to increase recycling rates advocated for in this study, will lead to significant sustainable benefits for all concerned.

Ultimately the success of any recycling initiative, like any other economic good, depends upon the availability of a market outlet, which is the primary incentive driving the activities of scavengers, and the dynamics of quality, price, location and timely availability. Unlike in the developed world, where detailed records of waste streams are held giving precise details of tonnages generated, it has not been possible to establish this for construction and demolition activities in Port Harcourt. Nevertheless, an indication of the large quantities of waste generated by construction and demolition activities can be deduced from the volume and pattern of private housing development and the level of construction output visible in the expanding metropolis. Planning authorities who record the scale of development in the area should therefore play an active role in managing the formal integration of scavengers as part of a formal waste management system. It has also been revealed, from both the interviews with waste buyers and from the grey literature evaluated as part of this study, that there is demand for CD waste which is often required for uses such as fill material, the construction of temporary structures for low-income earners, production of steel products such as utensils, for

decorative purposes such as in concrete mixes and finally for horticultural applications. This suggests a steady stream of uses readily exist for reclaimable and recyclable by-products. Against the backdrop of the high proportion of construction of new buildings, the missing link is the scavenger, who is needed to collect and sort the materials.

However, there are a number of constraints to the integration of scavengers which must first be overcome. The most critical is the health risk and lack of social acceptance, leading to stigmatisation of their activity, which has been a central point of debate in the literature. For example, Oguntoyinbo (2012) recognised scavenging as both a viable source of income and a means to the sustainable use of virgin resources. Whilst Wachukwu *et al.* (2010) opined that scavengers are carriers of deadly pathogens and represent a societal health risk and menace that needs to be curbed. The authors in this study are however of the opinion that addressing the working conditions of the informal sector would minimise the health risk, while formal recognition, organisation, and integration of the informal sector by training and certification to operate in these areas would boost their socio-economic acceptance. Ultimately both these solutions would enhance societal benefits and provide an initial framework around which environmentally sustainable waste management could be introduced to Nigeria.

CONCLUSION

This study has thrown intellectual limelight on the multiplicity of issues, including the social risk, health risk, occupational hazards, and lack of official recognition, facing informal sector recycling in Nigeria. This is against the backdrop of the harsh economic realities in Nigeria, which is characterized by high levels of poverty and unemployment, in which the scavenging community, with limited formal education and opportunities, operate. The study has shown that informal sector recyclers have the innate business acumen to eke out a living, by locating market outlet for waste, which otherwise would end up in landfills. The findings from the field work, has shown that the fast growing urban setting of Port Harcourt is ripe for integrating scavenging as a lucrative outlet for waste, based on the dynamics of supply and demand of CD waste currently prevailing. This is however subject to measures targeted at the formal recognition, organization, and improvement of the working conditions of the scavenging community, already in operation.

As a recommendation, scavengers can be required to obtain formal permits to operate in areas of High CD waste production, such as newly developing layouts, from local government authorities, who should work with the Rivers State Environmental Sanitation Agency (RSDA), responsible for refuse collection. Scavengers could thus be provided with uniforms, large push-carts, numbered and registered with the RSDA to operate in designated areas. This arrangement would be similar to the use of private refuse collection contractors who collect unsorted waste from dumpsites along roadways to landfills. However, the scavengers would be the primary collectors, responsible for sorting in their designated operational areas, before delivering the unrecyclable CD waste to dumpsites. Also suppliers of fill materials who use tippers to transport lateritic soil, (locally referred to as 'Red Mud') from burrow pits, could be engaged as part of the scavenging network. Scavenging thus represents a two edged sword, as a highly lucrative and environmentally sustainable outlet for CD waste, which is equally necessary to curtail the social consequences of unemployment and poverty. This is proposed as the necessary complimentary half, which should accompany an appropriate waste management plan, to be mandatorily prepared by developers as part of the approval process for building permit before the commencement of construction.

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BUILDING QUALITY: CONSEQUENCES OF FAILURE TO SEAL INFILTRATION AND EXFILTRATION PATHWAYS THROUGH THE FABRIC

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ABSTRACT

The Government's National Productivity Plan has set an ambitious target to build in excess of one million new homes in England by 2020. Homes that can be delivered to regulated quality standards are an essential part of the Plan. However, if the mass scale housing follows a similar process to those currently employed faults may be embedded within the fabric presenting future risks. Observations of current practice have revealed that many new buildings are inherently leaky, built with defects that result in underperforming building envelopes. A review of photographic evidence and supporting literature has revealed that where buildings have high levels of permeability, the integrity of the building envelope is compromised to a degree that could impact on its safe operation. The gaps, which are a result of ineffective interfaces and penetrations, allow air movement. The uncontrolled movement of air, through infiltration and exfiltration, deep into what may be termed the 'micro-structure' of the fabric has an impact on the thermal performance. More importantly, the air movement, within and between buildings also presents a hazard, increasing the risks associated with the movement of smoke and fire. The paper exposes the potential risks of infiltration and exfiltration and identifies common paths. The knowledge and skills required to avoid unwanted air movement within the structure, between internal and external faces, needs to be embedded into construction practice.

INTRODUCTION

Generalising about the building stock can be problematic, as buildings vary in design, size, characteristics and components; however, the causes of infiltration arise from some commonly occurring interface problems (Gorse 2016; Littlewood *et al* 2017). Interface problems and the quality of fit between building components is a topic that has long caused concern (CIRIA 1983). In the past, particularly between the 80s and 90s, such issues were often discussed under the term 'buildability', and particularly emphasised the difficulties arising from design and assembly problems. When components didn't fit together with ease, it was suggested to be a result of poor detailed design, which also had the potential to compromise efficiency, increase costs and also impact on safety (Illingworth, 2008). The concern with regard to a lack of coordination between design and contracting professionals to achieve safe workable solutions, has in part, led to the Construction (Design and Management) Regulations (CDM) 2007 and 2015 (Statutory Instruments 2007, 2015). While this legislative effort encouraged cooperation in design and construction practice the problems of building assembly persist. It is clear that the practice of construction has potential for further improvement ensuring that buildings are constructed with greater concern for their integrity, safe operation and sustainability.

The CDM regulations have focussed on safer construction and maintenance, sometimes with less consideration for the deficient construction assemblies that persist and result in performance gaps. Other regulated processes have also failed to support and deliver the expected standards. Building Control Bodies, are required to help ensure that all relevant building work accords with standards and guidance (DCLG 2014). When design and construction issues manifest building control officers are required to act independently and apply relevant standards (DCLG 2014). Recently, building control professionals were requested to be more vigilant and have an increased awareness of the performance gaps (Bowden 2016). This awareness campaign relates to thermal performance, but problems of function and fit, which affect thermal performance, can also impact on airtightness and moisture control (Gorse 2016; Littlewood and Smallwood 2016). The simple observable issues at the heart of this problem are often discussed but not clearly exposed.

A common issue is that voids occur where the interface between two components doesn't fit together properly. If these voids interconnect they can allow air into and through the building fabric, potentially bypassing any insulation; i.e. creating a thermal bypass (Stafford *et al* 2012a; 2012b; 2014; Hubbard 2011; Johnston *et al* 2009; Littlewood *et al* 2011; Littlewood 2013). Research on infiltration in dwellings has shown there is considerable variation in air tightness (Hubbard 2011; Johnston *et al* 2009; 2011; Stephen 1998; 2000) raising the question of the fabric's integrity. In addition to heat losses there are four further problems associated with air moving through the structure, via the bypasses. Firstly it introduces the problem of transporting aerosols containing liquids and solids, fungal spores, carbon, bacteria, pollen and other particulates. Secondly the flow of moisture, generated from internal sources can be transported into colder areas of the structure, which can result in interstitial condensation and mould growth. Thirdly gaps through separating elements will have a detrimental effect on their acoustic performance. Finally, and what is possibly of greater concern, is that unexpected air movement, which may assist fires, by allowing gases and vapours requisite for combustion through parts of the structure that are considered to be separated (Gorse *et al* 2015a), see table 1.

Table 1: Notable impact of uncontrolled movement of air within and through the building fabric

Impact of uncontrolled movement of air through the building fabric	
1. Thermal bypass	Air circulating through the structure carries heat energy.
2. Transportation of aerosols	Aerosols containing liquids and solids, fungal spores, carbon, bacteria, pollen and other particulates can be transported into the buildings micro fabric (creating problems for the future).
3. Transportation of moisture	Flow of moisture, generated from internal sources can be transported into colder areas of the structure, which can result in interstitial condensation and mould growth.
4. Transportation of air borne sound	Gaps in separating elements will have a detrimental effect on their acoustic performance.
5. Increased risk of combustion, spread of fire and smoke	Unexpected air movement, which may assist fires, by allowing gases and vapours requisite for combustion through parts of the structure that are considered to be separated.

The breach of fire resistant compartments and passage of air into concealed spaces was observed by Littlewood and Smallwood (2015; 2016) when conducting in-construction testing (iCT). The gaps in construction and ineffective edge seals may also allow the passage of smoke, should a fire occur. Shipp *et al* (2016) reported on analysis of building fires occurring between 2003 and 2013 and found that 32% had issues of fire spread due to defects in construction details, such as missing or inadequate fire stopping at junctions of compartment walls and also inadequate cavity barriers; and the main problems occurring in concealed spaces within buildings.

This paper investigates and discusses the implications of unplanned infiltration on fire safety on the 1 million homes planned under the National Productivity Plan (HM Treasury 2015).

Construction Integrity and Insulation

While there is an element of uncertainty with factors that impact on the performance of buildings, defects such as infiltration rates are measurable via blower door tests. The tests on small samples of buildings have shown relatively large variability, even where the building contractors and developers know air tightness tests are being undertaken. In Johnston *et al's* (2011) report, the performance of properties varied from 4.0 to 16.5 $m^3/(hm^2)$ @ 50Pa. Earlier work by Stephen (1998; 2000) considering larger samples reported much greater variance, from 2.0 to 30 $m^3/(hm^2)$ @ 50Pa.

The work of Johnston *et al* (2011) shows components not butting up and fitting together properly with air being allowed to move through the structure. Variation in material properties, defects that occur through packing and handling, workmanship issues, crushing and damage of materials, or poor fitting as a result of measurement errors all impact on the final performance (Aissani *et al* 2016; Domingues-Munoz *et al* 2010; Gorse *et al* 2015; Huang and Zhang 2014). Defects can also result from

'*design issues'*, often at the interface between components or structure changes; '*during construction'*, due to poor workmanship or inadequate quality processes; or as a result of '*operational life'*, including aging, settlement, shrinkage and expansion (through temperature, moisture and chemical attack) or as a result of impact damage (Aissani *et al* 2016; Littlewood 2013; Littlewood *et al* 2016). All of these issues are thrown into a field of defects that impact on performance. Where defects are recognisable during the construction phase they should be identified and corrected to ensure the risk associated with the impact and consequence of the defect is minimised.

Build Quality

High energy and airtightness performance targets can be met, the buildings that meet the relevant standards in whole-house heat loss studies confirms this (Stafford *et al* 2012a; 2012b). While the work identifies defects in properties, the same body of research from which these observations have been made have also identified examples of good practice. The work reported by Johnston *et al* (2014; 2015) distinguishes between those buildings that have achieved high, expected, standards of fabric and energy performance and those which present a performance gap.

Buildings that meet their design standard show limited evidence of unintended bypass, air leakage and thermal bridging. It is evident that buildings that offer effective thermal barriers resist air movement and provide more consistent and reliable fabric behaviour; however those that allow heat and air movement also have implications for fire and smoke safety. The research indicates that there is a considerable discrepancy between design intentions and as-built performance, which are seldom accounted for by margin of error alone (Gorse *et al* 2016a; 2016b; Littlewood & Smallwood 2015).

Fire Safety

Variations in thermal performance can often be an indication of non-compliant build standards, with buildings also failing to properly address acoustic and fire standards (Littlewood & Smallwood 2015). Littlewood's research following the iCT methodology, when conducting air permeability tests combined with whole dwelling smoke tests (used for air tightness compliance), found that air leakage paths resulting from breaks in the insulation and penetrations in the fabric that connected to neighbouring properties, allowed the passage of smoke from one property to the next, into concealed spaces, roof spaces and into areas designated as means of escape. The passage of smoke occurred generally in minutes and thus questions the ability for these properties to achieve the minimum smoke/fire resistance of between 30 and 60 minutes. The properties tested included two-storey houses, and multi-storey apartment buildings. The paths that breach fire barriers, compromise the basis of compartmentation which is used to ensure sufficient time for evacuation, in the event of a fire, is maintained.

Part L of the Building Regulations (HM Government 2016) stipulates that when cavity barriers are used for edge sealing purposes, then the seal must be effective at restricting air flow between the party wall cavity and the external wall cavity. The Building Control Alliance (2011) describes how an edge seal is to be judged as being effective in a qualitative manner, stipulating the various ways in which an insulation material can practically fill and effectively seal the cavity. The guidance calls for the insulation seal to be impermeable to the passage of air and moisture, seal both leaves of a wall, have continuous runs, be in line with the thermal envelope and be flexible to accommodate

construction undulations. As an additional note they describe that any unintended gaps in the insulation due to imperfections are deemed acceptable providing that any gaps don't create an uninterrupted path between wall junctions, elements and components. While such descriptions are useful, however, it is of some concern that there are no current standard test to quantitatively demonstrate the effectiveness of edge sealing using a cavity barrier. Research undertaken by Gorse *et al* (2015), which exposed the different degrees of effectiveness of cavity barriers, has explored a number of options for observing and testing the effectiveness of cavity barriers. The use of tests and inspection procedures would prove useful when engaging designers, building control bodies and warranty providers, who would benefit from assurance that barriers and the fabric are effective.

Assuring the Quality of New Housing

With the scale of the UK National Productivity programme proposed, it is important that the homes produced remain robust, affordable, allow safe operation (provide safe means of escape in the event of a fire – min 30 to 60 minutes) and sustain their economic value and performance over time. However, for buildings to sustain their economic value they need to be considered free from defects, especially those defects that may be detrimental to the safe operation of the property.

While the economic value of a property is linked to location, style and size, the sustained value of a building is also linked to the product's ability to function safely. The performance and condition of the property are linked, by survey and assessment, to its value, and the case law evidence has set a precedent on the impact of defects and the resulting value (for example, see Gilbert 2015). A defect that could render a building unsafe would be considered a major defect. During resale, in most cases, major defects need to be addressed or the price reduced (Gilbert 2015). Hidden defects are also likely to pose a financial and safety risk (Ship *et al* 2016; Littlewood *et al* 2017). Those defects that remain hidden and could not be reasonably discovered at the time of handover or during initial inspection will be classed as latent defects and thus, the responsibility for rectifying the defect, would exceed the normal defects liability period. The liability period under the Act, in most instances, would commence at the point of the defects discovery (Latent Damages Act 1986; Elias 1990). Contractors and developers can't rely on the protection of the defects liability period where their defects are covered up (eg where the defects are hidden from sight or not obvious through normal practice). Where defects have implications on the building operation, health and safety of occupants and value of the building, it would be prudent to avoid or rectify defects early in the design and construction process. Where such issues are known about but not adequately addressed by designer, inspectors or advisors issues of professional negligence may also be considered. The impact of the defects and the risk they pose to the safe operation of the building could result in significant remediation work and would carry associated costs. The work reported here focuses on the recognition and removal of known defects rather than the legal and financial consequences, although the direct links that can be made to such consequences are worthy of note. The focus in this research is on the recognition of defects, to alert built environment professionals to the defects that can be observed and thus provide a remedy so that financial and legal risks can be avoided.

RESEARCH AND OBSERVATION METHOD

Data has been gathered through field work, primarily investigating the energy efficiency of dwellings from the following projects:

Joseph Rowntree Housing Trust Temple Avenue Projects and Technical Reports and images (CeBE 2015; Miles-Shenton *et al* 2010; Miles Shenton *et al* 2011)
Stamford Brook reports and images (Wingfield *et al* 2011; Sutton *et al* 2014; CeBE 2015)
DECC Core Cities reports, images and feedback (Gorse *et al* 2014)
ARC T Barrier reports, images and feedback (Gorse *et al* 2015a)

Building surveys and forensic investigations were undertaken to determine why buildings underperformed and to identify factors contributing to variations in expected energy behaviour. The detail of the tests and monitoring used are described in the reports cited above. Also during the studies, photographic surveys were undertaken during the construction of new buildings. Photographs were taken of junctions and plane elements, as well as more specific photographs at points of interest. While used initially for energy efficiency and air tightness investigations, here they are used to report and describe defects that affect the integrity of the building fabric. Of specific concern are discontinuities in the fabric that have potential for air leakage, infiltration, exfiltration and bypass. A link is postulated that such weaknesses in the fabric, where air movement is possible, has the potential to carry moisture, smoke, oxygen (fuel for the passage of fire) and other materials including particulates. At this stage the research is developmental, observing the defects and exploring the possible consequences, through the literature. The work does not seek to recognise the extent to which the building fabric is compromised.

CRITICAL ANALYSIS

A vast body of photographic data has been collected. The selection of photographs and details for further examination were based on a critical analysis – using research experience, applied learning and informed knowledge to make reasoned judgments, when selecting photographs. Viewing all of the photographs as they are uploaded and evaluating the image for its observation of a phenomena of interest was used as the first pass for selecting images. Each image was considered with a view to its ability to communicate meaning and expose the defect. The image had to possess the capability to expose a situation and convey practical and usable information to the reader. The basic observation and selection of the images provided a simple critical system for selecting images which help to demonstrate the problem.

Critical analysis is based on the critical thinking movement (Elkins 1999) and reasoned judgements. The procedure when evaluating construction images was to rationalise and contextualise the problem, understand the importance of the issues, recognise assumptions and interpret data to appraise the evidence, recognise the existence of relationships, draw generalisations, construct patterns and render accurate judgements. Using these qualitative observations, the work does not provide information on the representative nature of the faults identified; however, based on the research it was noted that such instances observed were not uncommon in the studies undertaken and are expected to occur in other situations and sites.

SUMMARY OF OBSERVATIONS AND FINDINGS

The following observations provide a visual indication of the weaknesses and faults found.

Gaps in masonry cavities

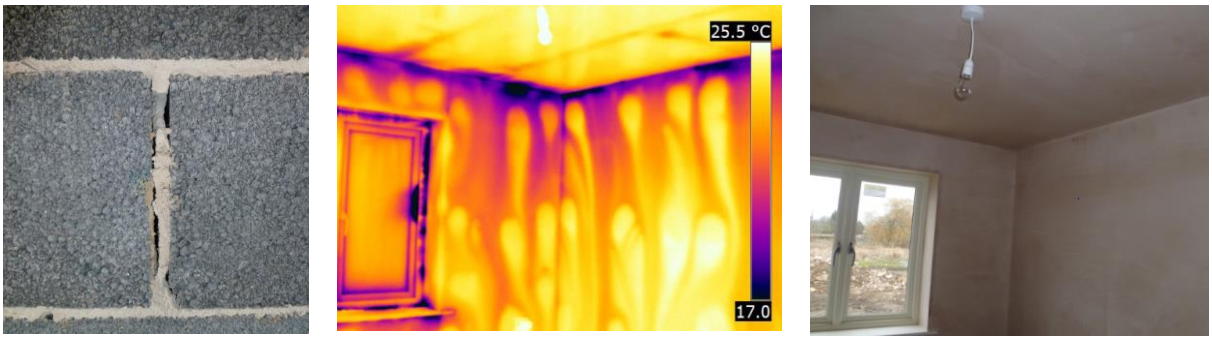

Figure 1. Infiltration through the blockwork and penetrations (Johnston et al 2011; Farmer et al 2014)

Figure 1 shows joints within masonry that are not fully filled. These are a common occurrence on site. When buildings are depressurised using a blower door, the impact of unfilled joints allows air through the masonry, also at the intersections of the floors where penetrations into the wall from the floor are high infiltration is particularly notable. Also see the images in Figure 4, which show photographic evidence of the construction of floors and penetrations of joists through walls.

The thermal image (in Figure 1) shows the impact of both indirect and direct air infiltration; indirectly, with air being drawn from the unconditioned loft space above the property into the void behind the dry lining, and directly, with external air entering into the building fabric around and through the window frame. The prominent cold areas, shown by deeper shading, are particularly prominent at the interface between the wall and ceiling and between the window and wall.

Of concern, in the image, is the manner in which the air voids are connecting. Cold air paths can be seen coming from the external wall, presumably penetrating the cavity, then through connecting voids, being particularly prominent at the floor void interface. The cold air is also passing between the internal blockwork and dry-lining.
In some cases, wet plaster, or a parging coat has been used to offer a more effective seal and to reduce the air movement.

Service entry and penetrations through the wall

Figure 2. Service penetrations through fabric (source Johnston et al 2011)

Where products have not been measured correctly, or where the placement of services are loosely positioned and then not sealed, air movement and bypasses are possible. Oversized holes may sometimes be necessary, to allow sufficient space to insert the services and fill the interface void with an effective seal. The images shown were not oversized to allow for seals to be inserted, but are evidence of inadequate practice that results in large gaps. Some fittings, collars and finishes make it difficult to access the areas that need to be filled and prevent penetrations being sealed. Care needs to be given to building assemblies so that areas can be accessed and sufficient seals inserted. In most cases observed there was little consideration given to the sealing of service penetrations, particularly at the point at which it penetrated the air barrier.

Interface at wall opening

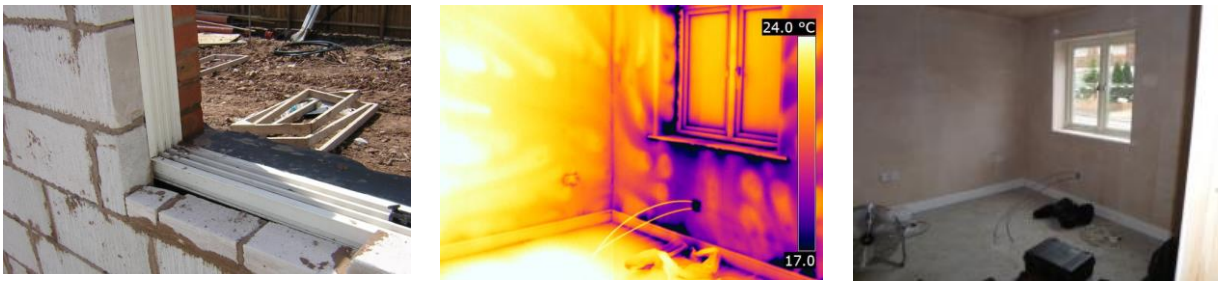

Figure 3. Air leakage due to ineffective seals at wall openings (source Smith et al 2005; Farmer et al 2014)

Interface problems at wall openings such as windows and doors, often present a problem with regard to effectively sealing. While the photograph shows masonry which has been poorly cut and does not properly meet the cavity closer, it is also noted that materials often used at such interfaces are rigid, without an ability to meet and fill undulations between the two surfaces. Where compressible interfaces or more resilient materials are used, the seals may be more effective.

Poor cut and fitting components, concealed assemblies

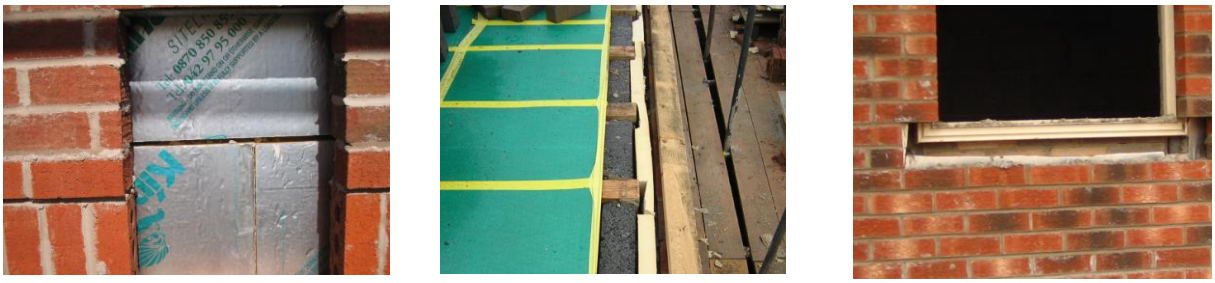

Figure 4. Poor installation and fitting of fabric which are concealed (source Johnston et al 2011; Smith et al 2005)

Figure 4 shows poor fitting between insulation and the interfaces with other components, this allows voids to connect and air penetration within and through the fabric to become possible.

Poor workmanship

Figure 5. Poor workmanship, joints and debris making effective joints difficult (source Johnston *et al* 2011; Smith *et al* 2005)

Workmanship is one of the main areas of concern. Components not properly fitted, snotts and debris left in the cavity are common errors which create problems. Ill fitting fire barriers, insulation, masonry and timber present major problems to the fabric integrity allowing air penetration and breaching fire barriers. The 'shody workmanship' shown in Figure 5, where materials are thrown into place with little consideration for the quality of assembly was found on a number of the studies. Such practice should not occur on sites in the 21st century, the integrity of the whole building can be questioned where the construction practice is so poor. The images raise concern with regard to on site skills, supervision and inspection, and whether such practice is a result of the skills gap, with the trades and superviory team operating with inadequate skill and knowledge (evidence of skills gap is often cited CITB 2015).

Good Practice

Figure 6. Examples of sealed masonry and good practice (source Johnston et al 2011)

Where building are constructed with care, there is a significant difference in the manner that materials are fitted and sealed. The construction appears neat and clean (Figure 6). The workmanship shown in the above photographs is in stark contract to that shown in previous images.

DISCUSSION

The photographic evidence and thermal surveys collected by the research team show problems of component interface, ill-fitting seals, breaks in construction, fabric cluttered with debris and missing insulation that contribute to variations performance and also expose bypasses and interconnecting voids that may compromise fire safety. Evidence of construction assemblies in the field is now relatively easy to collect with the advances in mobile imaging and photography equipment.

Evidence suggests that in the cases observed the current build processes are flawed and susceptible to variation in quality and performance. Attention needs to be directed at design, construction and commission practice to ensure all new building forms are robust before occupancy and use, the whole building smoke test could be used to check for compartment and dwelling bypasses.

Some of the gaps in performance are relatively small and may be within an acceptable level of tolerance. Where the earlier literature refers to air leakage below 10 $m^3/(hm^2)$ @ 50Pa air filtration is considered satisfactory and the factors reported would be minimal. However, where test results are well outside normal tolerance, more than double that regulated, they are indicative of inadequate construction processes and the permeability infiltration defects are probably embedded within the structure. Non-destructive tests and survey methods, such as the use of a thermal camera and a blower door, during heated conditions, to indicate infiltration paths could help inform the extent of defects.

Insight gained through the investigations into thermal performance have revealed whole building assemblies that are a potential concern with regard to problems of air tightness. The integrity of the external envelope and effective interfaces between components affect many aspects of performance. Most of the problems identified can be addressed by good practice, changes to design, workmanship and an evidence based quality processes.

Much of the research provides evidence of missing or ill-fitting components and assemblies that are different to that designed and cannot be put down to acceptable error. A growing body of evidence

identifies non-compliance and failure to adhere to quality processes. A simple, standardised evidenced based method for building compliance is required. With current technology, evidence of build quality can be assured and cross-checked to buildings by geo and date tagging. Such building information will ensure future maintenance is appropriate and not cost-prohibitive.

A number of new build properties have achieved their performance targets, showing their air tightness and thermal integrity is good. As buildings manage to achieve their expected performance when built, attention should focus on the design, construction and quality processes used to achieve such results. A few organisations are investing in prototype schemes where they learn, develop and improve their design and construction process (for example, Hill reported in the Cambridge News 2015; and the Temple Avenue projects, CeBE 2010; Miles-Shenton *et al* 2010; Miles Shenton *et al* 2011). The systematic use of prototype buildings, that can inform large scale programmes and incrementally develop build processes and quality products are useful. Prototype and version development adopted by many other industries should be encouraged within the house building sector.

The home represents a significant investment. Evidence of practice that assures build quality could have an impact on the future value of the building. Cost secure, smoke & fire safe, energy efficient homes are most likely to be delivered through quality driven standardised or manufactured processes. Further work should be undertaken in this area to explore the full implications and potential solutions.

Assembly Evidence

As the cost and availability of photographic and thermal image technology is within site reach, it is not unrealistic that evidence of build quality could be provided for each property. Simple geotagged images could replace signatures of compliance, reduce bureaucracy and improve conformance. Smart phones, tablets and their apps can all record such data.

As there is a considerable increase in the technology that can be readily accessed to monitor and measure building performance, consumers have greater power to understand the behaviour of their homes and the degree to which they respond to change and user requirements. As environmental and energy assessment apps are now available to consumers and are steadily becoming more sophisticated, as intelligent algorithms are developed to interpret and separate out data, as researchers develop the ability to disaggregate building fabric, system and occupant data, the home owner will have the power to determine whether the building fabric is fit for purpose and performing. Indications of weakness in the air barrier could well represent a weakness in the fabric integrity and its ability to resist the passage of fire and smoke.

The processes and measures used by industry should ensure that the quality of the building is fit for purpose, robust, ensures the government's carbon commitments are not compromised and meets the demand required by its clients.

Economically Viable Homes and Long Term Consequence of Poor Performance

The purchase price, rent, operation and maintenance costs are a concern for a large proportion of the population. However, and rather surprisingly, where buildings are poorly constructed, being

energy and resource intensive to operate, the evidence of rebuild or remedial correction to address the operational cost is relatively thin. The building industry does not have a reputation of recalling and systematically correcting faults related to energy consumption.

Once buildings are occupied, the ability to undertake systematic improvement, remedial work or retrofit can be difficult. The social values linked to buildings are complex and building retrofit can sometimes be at odds with the economic viability of the property (for example, see Crawford *et al* 2014 work on the choices associated with demolition or refurbishment of social housing).

If new homes continue to be poorly constructed the UK will bear the operational costs, maintenance costs and impact upon occupants for some time. Such costs are borne by the nation as many of those that live within fuel poverty brackets are unable to support living costs unaided (evidence of this can be found in MacInnes *et al* 2015 report on poverty), also the cost associated with fire affect insurance premiums (The Geneva Association 2014) where fire risks are high. If properties do need retrofitting, the cost of maintaining and refurbing the building will be incurred.

The price of a house is not necessarily a good reflection of build quality. During the last five years for many groups, access to housing has become worse (MacInnes *et al* 2015). Whilst the demand for housing has steadily inflated the purchase price (Halifax House Price Index 2016), this is not necessarily reflected in the quality of build. Evidence of under-performance is consistently found in new buildings (Gorse *et al* 2015; Littlewood and Smallwood 2015; 2016; Johnston *et al* 2015). The liability for the cases set out above has yet to be fully realised, but the potential implications on build value and costs should raise a level of concern.

CONCLUSION

The photographic evidence of the few cases shown here provides confirmation that problems exist, can be observed and should be resolved (Table 2). Building performance and integrity are only likely to affect the value of homes when the operational costs become a burden, defects occur or defects are recognised as part of a building survey (building surveys may be required to support the release of a loan or mortgage). Subsequently, remedial costs, to correct defects, may also be incurred if current practices are not changed. Quantitative evidence shows that the air permeability of buildings is variable, and while initial data collection was motivated through energy efficiency research, the more immediate concern of fire safety should also be considered. Further research is necessary to explore the influence that air paths have on fire and smoke transfer; not only on the potential financial and energy efficiency implications, but also on what renders an unacceptable risk to those that use the building.

Problems with design and construction coordination
Ineffective edge seals
Ineffective assembly and fitting, gaps in construction
Interface problems (materials don’t fit together easily)
Difficult installation and seals (problems of access in concealed areas
Poor workmanship
Service coordination and fitting
Lack of adequate inspection and commissioning tests

Table 2, Problems observed that lead to air infiltration and exfiltration

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REDUCING EMBODIED CARBON IN THE BUILT ENVIRONMENT: A RESEARCH AGENDA

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ABSTRACT

In spite of significant global efforts, the International Energy Agency suggests that buildings-related emissions are on track to double by 2050. Whilst operational energy efficiency continues to receive significant attention by researchers, a less well-researched area is the assessment of embodied carbon in the built environment in order to understand where the greatest opportunities for its mitigation and reduction lie. This paper reports on available mitigation strategies to tackle embodied carbon identified through a systematic review of the available academic evidence. It also investigates the scope and scale of current academic investigations to highlight where significant gaps are for impactful further research on the topic. In total, 17 mitigation strategies have been identified from within the existing literature which have been discussed individually. Results reveal that a one-size-fits-all approach is unlikely to yield beneficial results and future research should be diverse in breadth and scope, locally accurate, and significantly interdisciplinary.

INTRODUCTION AND THEORETICAL BACKGROUND

The built environment puts incredible pressure on the natural environment. In the European Union, it accounts for 50% of all extracted materials, 42% of the final energy consumption, 35% of greenhouse gases (GHGs) emissions (EC, 2011) and 32% of waste flows (EEA, 2012), and global figures are not much different (Khasreen et al., 2009). Considerable effort across policy, academia and industry has therefore gone into improving the energy efficiency of buildings. However, until recently political effort has focused almost entirely on the operational stage (occupancy phase) of buildings, with one example being the European Union final deadline for nearly Zero Energy Buildings (nZEB) from 2020 (EU, 2010). The reason given for this focus is that operational energy (and carbon) accounts for the greatest share of life cycle energy (and carbon) of a building.

In spite of these efforts CO_2 emissions are continuing to rise, with the International Energy Agency (IEA) suggesting that emissions are on track to double by 2050 (IEA, 2014). Part of the reason appears to be that the higher energy efficiency leads to rebound effects from increased energy demand, due to, for instance, "more heated space, higher temperatures, and for longer periods" (Rovers, 2014). However a less well-researched reason may be due to the unnecessary dichotomy between operational and embodied impacts, which has the unintended consequences both of ignoring the effects of increased construction and in some cases of shifting the environmental burdens from one life cycle stage (occupancy) to the others (Pomponi et al., 2016a). There is now robust evidence that the embodied impacts of buildings are a significant contributor to global emissions, and that as a percentage of whole life impacts of buildings they can account for more than 50% (Crawford, 2011), with 70% calculated for some cases in the UK (Ibn-Mohammed et al., 2013).

Out of several potential measures, 'embodied carbon equivalent' (CO_{2e}[1]) is useful for several relevant reasons:

- It measures and indicates the contribution of buildings and their products to global warming and climate change, which is increasingly critical (Moncaster, 2015, IPCC, 2014);
- Through considering the carbon intensity of the energy carrier it is more comprehensive than embodied energy (Pomponi et al., 2015);
- While it may not accurately represent all additional ecological and environmental impacts (Pomponi et al., 2016a, Asdrubali et al., 2015a, Turconi et al., 2013), it correlates well with several impact categories of more comprehensive impact assessment methods (e.g. ReCiPe) (Heinonen et al., 2016), thus acting as a useful indicator also for impacts other than climate change.

The substantial growth of related literature from outside academia (ASPB, 2014, RICS, 2012, UKGBC, 2015, IEA, 2016, ICE, 2015, BRE, 2015), which addresses the themes of EC reduction and mitigation, also confirms the importance of embodied carbon.

In spite of this growing interest and understanding of the issue, the body of academic knowledge on strategies to tackle embodied carbon has not previously been investigated systematically. This paper reports on previous research by the authors (Pomponi and Moncaster, 2016) and presents seventeen

[1] Carbon dioxide equivalent emissions, measuring unit of the Global Warming Indicator (GWI)

mitigation strategies that have been identified to address embodied carbon reduction in the built environment.

The following section introduces the method whereas section three discusses each of the mitigation strategies identified and includes the meta-analysis of all collected data to identify existing trends and issues. The fourth section concludes the paper.

METHODOLOGY AND METHODS

The choice of a systematic approach to review the existing literature is done to ensure thoroughness, rigour and objectivity. This approach is widely used in other disciplines (Tranfield et al., 2003, Delbufalo, 2012) but also in built environment research (Pomponi et al., 2016b). A further technique often combined with this process is the meta-analysis of data to quantitatively integrate research findings across a wide number of studies (Delbufalo, 2012) in order to reveal and map significant trends (Pomponi et al., 2016b) through the harmonised use of reviewed data (Asdrubali et al., 2015a, Pomponi et al., 2016b). Ultimately, the purpose of a systematic literature review and meta-analysis is to make sense of key elements within a large collection of sometimes-contradictory studies to facilitate decision-making and action with an aim to inform both policymaking and practice (Tranfield et al., 2003).

In this paper the following strings[2] and combinations thereof have been searched across main literature database[3]:

- Embodied carbon mitigation (+strategy)
- Embodied carbon reduction (+strategy)
- Embodied carbon management (+strategy)
- Embodied carbon building(s)
- Life cycle assessment building(s)
- LCA building(s)
- Life cycle carbon building(s)

Due to the rapidly developing field, search results were temporally limited to 10 years and given existing disputes over reliability, data quality, and system boundaries within LCA, results were also limited to peer-reviewed journal articles. In total, after removing duplicates, 876 manuscripts matched the initial search criteria but only 102 were eventually relevant to this research. Due to the page limit for this paper it was not possible to report all details of the studies reviewed but the interested reader could refer to the full article of the extensive research for more information (Pomponi and Moncaster, 2016).

EMBODIED CARBON MITIGATION STRATEGIES

Seventeen mitigation strategies (MSs) were identified in the reviewed literature, which are presented and discussed in turn.

[2] The search was limited to Title, Abstract, and Keywords of manuscripts to avoid completely unrelated results.

[3] Web of Knowledge, Web of Science, Science Direct and Google Scholar.

MS1: Use of materials with lower embodied energy and carbon

The use of alternative materials with low EE and EC to mitigate the contribution of the built environment to climate change was a particularly common solution (e.g. Yu et al., 2011, Ng et al., 2012). In many studies, this approach involves the use of natural materials (e.g. timber, bamboo, hemp-lime composites). For instance, Reddy (2009) investigated the use of stabilised mud blocks (SMB) as a substitute for load bearing brickwork and found nearly a 50% reduction in embodied costs. With a focus on using alternative building materials over more traditional ones for a 28-storey residential building in Hong Kong, Cui et al. (2011) quantified the related embodied carbon savings, obtaining a 34.8% reduction. Switching from material level to a full house project, Salazar and Meil (2009) assessed the GHG impacts of what they call a 'wood-intensive' house in comparison to a typical one with brick cladding in Canada and found extremely significant differences between the two: 20 tCO_{2e} for the former vs. 72 tCO_{2e} of the latter. The enormous potential of a broader adoption of wood as a construction material seems confirmed by Upton et al. (2008) who, in a US residential-sector-wide study, indicated savings of 9.6 $MtCO_{2e}$/annum by using wood as an alternative to concrete- and steel-based building systems under the assumption of 1.5 million single-family new houses built each year. Vukotic et al. (2010) also found a timber structure school building to have lower impacts than the steel frame alternative, but recommend that "rather than encouraging debate about which material is 'better' than any other", the best use is made of chosen materials in any particular situation (Vukotic et al., 2010). It is worth noting that in some comparative studies, the use of materials with lower EE/EC may also involve commonly-used materials, such as in the work of You et al. (2011) who found a 4.2% CO_2 reduction in preferring steel-concrete structures over masonry-concrete structures; an aspect which leads to the importance of design discussed in the next sub-section.

MS2: Better design

Good design practice and appropriate choices at the design stage, as well as techniques such as design for deconstruction, were identified as crucial strategies for EC reduction and mitigation. Acquaye and Duffy (2010) conducted an input-output analysis of the Irish construction sector; they suggest that their results showed that better design could have reduced indirect emissions by 20% and direct emissions by 1.6% totalling 3.43 $MtCO_{2e}$. In examining refurbishment of high-rise concrete buildings in Hong Kong, Chau et al. (2012) also found a determinant role of design. They argued that "the most effective option is to maintain 15-30% of the existing structural and non-structural building elements as it can reduce the CO2 footprint by 17.3%". This view is echoed and supported by Cuéllar-Franca and Azapagic (2012) who reflect on the longevity of decisions taken at the design stage and call for a sustainable home design which considers the impact that design choices exert over the building's life cycle. The centrality of design is also emphasised by Häkkinen et al. (2015) who recommend a gradual and systematic procession through all different phases and stages of design to accurately assess GHG emissions and achieve low-carbon buildings.

MS3: Reduction, re-use and recovery of EE/EC intensive construction materials

Basbagill et al. (2013) investigated in detail the application of LCA to help designers understand and reduce the environmental impacts of building materials and components. They found that by optimising key parameters (e.g. thickness of piles and footings, and of external and internal walls) "anywhere from 63% to 75% reduction in the building's maximum total embodied impact is possible"

(Basbagill et al., 2013). Garcia-Segura et al. (2014) assessed the reduction of GHG emissions due to a reduced use of Portland cement and its substitution with blended cement, which has a higher content of fly ash (FA) and blast furnace slag (BFS). Such an approach promises to lead to 7% - 20% fewer emissions (Garcia-Segura et al., 2014). Similar environmental benefits following a reduction in use of cement are echoed by Atmaca and Atmaca (2015) and Miller and Doh (2015). Moynihan and Allwood (2014) investigated the utilisation of structural steel in buildings and concluded that by designing to minimise the material used rather than the cost, the use of steel in building and the associated embodied impacts could be dramatically reduced.

MS4: Tools, methods, and methodologies

Despite the populated panorama of existing tools, assessment methods and methodology, it still seems this is seen as a key area to bring about embodied carbon reduction with the parallel aim of building a better and stronger EC culture amongst the built environment stakeholders. This may take the form of coupling EC assessment with building information modelling (BIM) (Ariyaratne and Moncaster, 2014) or combining BIM with dynamic energy simulation tools (Peng, 2016). In some other cases, new methodologies aim at refining existing ones by, for example, coupling a life cycle carbon assessment with an analysis of the value created by the specific activity/product under investigation (Li et al., 2013).

MS5: Policy and regulations (Governments)

Perhaps unsurprisingly, the implementation and/or revision of policy and regulations by Governments also emerged as a commonly cited strategy for EC reduction (e.g. Dakwale et al., 2011, Blengini and Di Carlo, 2010, Giesekam et al., 2014). In some studies (Giesekam et al., 2014) this strategy is mainly intended as a means to support other mitigation strategies, like a wider use of low EE/EC materials, whereas in others policy has a broader reach. For instance, Dhakal (2010) reports on Chinese and Japanese contexts where a 50% CO_2 reduction could be achieved through the impact of policies on design and construction practices.

MS6: Refurbishment of existing buildings

A few scholars believe the greatest opportunity for EC mitigation lies with the upkeep of existing buildings. This appears to be especially true in developed countries where the existing building stock forms the vast majority of the built environment. Gaspar and Santos (2015) assessed the potential saving for a detached house in Portugal built in the late 1960s, concluding that refurbishment would be 22% more efficient than demolition and rebuild. A strong case for refurbishments can be also found in the work of Power, who demonstrated that the case for large scale demolitions “is greatly weakened” when considering EC as well as operational figures, for the EC of an average refurbishment project to bring an existing house up to modern standards is around one third of that of a new house (Power, 2008, Power, 2010).

MS7: Decarbonisation of energy supply/grid

Just as the idea of decarbonising the energy supply is seen as one pathway to operational-carbon-free buildings (Rovers, 2014), some scholars point out that there is the same opportunity for embodied costs (Chang et al., 2011, Heinonen et al., 2011, Jiang and Tovey, 2009). For instance, in

the study from Heinonen et al. (2011) a specific 'greener' energy mix would cut 6% off the total emissions figure.

MS8: Inclusion of waste, by-product, and used materials into building materials

A further beneficial effect may be brought about by the inclusion of waste and by-products into building materials (e.g. Lee et al., 2011, Napolano et al., 2015), in light of cradle-to-cradle design and circular economy approaches which have recently received increased attention as a valid and viable alternative to the traditional linear make-use-dispose paradigm. Intini and Kuehtz (2011) investigated the use of recycled plastic bottles to manufacture thermal insulation in Italy and concluded that recycled polyethylene terephthalate (PET) can reduce environmental impact as much as 46% with respect to GWP. Some researchers also highlight the importance of considering the necessary supply chain to realise this (Densley Tingley and Davison, 2011).

MS9: Increased use of local materials

Several studies reported the EC reduction due to an increased use of local materials which would reduce transportation impacts (e.g. Asdrubali et al., 2015b, Chou and Yeh, 2015, Gustavsson et al., 2010). In a detailed assessment of stone production carried out in accordance to PAS 2050 guidelines, Crishna et al. (2011) argued that depending on the stone type and the country of origin, the use of UK-based stones can save between 2% - 84% of the EC of stones sourced from abroad. It is also worth considering that such strategy would benefit local or national economies as well as the environment.

MS10: Policy and regulations (Construction sector)

For some scholars, the strength of policies and regulations lies not (or at least not only) with governments but with bodies and stakeholders within the construction sectors (e.g. Acquaye and Duffy, 2010, Alshamrani et al., 2014). For instance, Alshamrani et al. (2014) developed an integrated LCA – LEED model for sustainability assessment and believe there would be positive consequences if it were voluntarily adopted and used in the construction sector.

MS11: Social 'component' - change driven by strong demand from all BE stakeholders

This cluster groups 'social' elements for a built environment with lower EC, such as an aesthetic demand for "buildings [with] sustainable credentials" (Monahan and Powell, 2011), or solutions related to people's skills such as the contractors' ability to plan resources, their management skills and construction performance mentioned by Sandanayake et al. (2016). Also, social or cultural aspects have been identified as barriers to EC reduction, such as the inertia of builders towards environmentally conscious regulations in China reported by Li and Colombier (2009).

MS12: More efficient construction processes/techniques

In some studies, a gain in efficiency in the construction sector is seen as an important opportunity for EC reduction (e.g. Sandanayake et al., 2016, Roberts, 2008, Monahan and Powell, 2011). This is often intended as a more efficient manufacture of building materials, the use of innovative and less wasteful processes during the construction stage, or a combination of the two. This strategy also includes the reduction of delays, the impact of site conditions, and the use of more energy efficient machinery.

MS13: Carbon mitigation offsets, emissions trading, and carbon tax

Some scholars see the solution to the EC problem in carbon mitigation and trading, and in fewer cases carbon taxing. For instance, Dalene (2012) reports on a case study of a residential building where all "GHG emissions were offset by carbon mitigation programs and certified carbon offsets were purchased" to achieve carbon neutral status. At a broader scale, Kennedy and Sgouridis (2011) developed a carbon accounting framework for cities to categorise and determine urban emissions strategies.

MS14: Carbon sequestration

The carbon sequestration approach found in few studies (e.g. Dhakal, 2010, Gustavsson et al., 2006) is to some extent linked to the previous strategy but it deserves a separate category due to different underlying principles: while carbon offsets and emissions trading offer a policy solution to EC reduction, carbon sequestration looks at the technological side of the issue exploring new materials or innovative uses of existing ones to capture and store carbon. For instance, Sodagar et al. (2011) studied the use of biotic materials in a social housing project in the UK and concluded that the carbon lock-up potential could reduce carbon emissions by 61% over the 60-year lifespan of the houses.

MS15: Extending the building's life

Intuitively, extending a building's life span would delay and therefore reduce the EC associated with deconstruction and demolition, waste processing and rebuild. However, this strategy is only considered by a handful of studies in the existing literature (e.g. Densley Tingley and Davison, 2011, Toller et al., 2011, Yung and Chan, 2012). In some of the studies, this strategy does not simply consider aiming for a longer service life of the building but is also about designing the building with the necessary flexibility to be durable and adaptable.

MS16: Increased use of prefabricated elements/off-site manufacturing

This category is somewhat linked to more efficient construction processes but due to a clear stream within the existing literature oriented towards off-site manufacturing and prefabrication it was coded separately. In some studies, the emission savings of this strategy alone have been quantified. For instance Mao et al. (2013) found that semi-prefabrication would emit 3.2% less than conventional construction. Off-site manufacturing has been also investigated in combination with other strategies (e.g. the use of low embodied carbon materials) such as in the case of Monahan and Powell (2011).

MS17: Demolition and rebuild

In a very few cases, such as Dubois and Allacker (2015), it has been suggested that a truly significant carbon reduction in the built environment would only be achievable through wide campaigns of demolition and reconstruction with the belief that embodied costs of such activities are negligible compared to the benefits of new build. In another study (Boardman, 2007), a demolition level higher than current practice is considered a "sensible compromise" to tackle climate change.

Table 1 shows the meta-analysis done on the correlation across all mitigation strategies (blue = higher correlation / red = lower correlation).

As evident in Table 1 some MSs are more strongly correlated with others. It is important to clarify that low or null correlation does not necessarily mean that there is not a synergy to exploit between a specific pair of MSs but might as well mean that the potential has not yet been investigated. As such, those specific pairs of MSs are interesting avenues for further collaborative and interdisciplinary research.

Table 1 - Meta Analysis of Correlation Across All Mitigation Strategies

MS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	100%	47%	43%	27%	20%	14%	20%	18%	18%	10%	12%	8%	4%	10%	10%	6%	0%
2		100%	48%	38%	27%	23%	21%	21%	8%	21%	13%	8%	13%	8%	10%	2%	2%
3			100%	29%	10%	24%	10%	24%	14%	2%	5%	5%	5%	10%	12%	5%	0%
4				100%	30%	9%	12%	12%	6%	24%	18%	0%	9%	6%	6%	0%	0%
5					100%	25%	25%	8%	4%	29%	33%	8%	21%	8%	8%	0%	8%
6						100%	16%	11%	16%	5%	16%	5%	5%	11%	5%	5%	0%
7							100%	13%	19%	6%	19%	6%	6%	13%	6%	6%	0%
8								100%	20%	7%	20%	7%	7%	13%	7%	7%	0%
9									100%	8%	23%	8%	8%	15%	8%	8%	0%
10										100%	25%	8%	8%	17%	8%	8%	0%
11											100%	8%	8%	17%	8%	8%	0%
12												100%	11%	22%	11%	11%	0%
13													100%	22%	11%	11%	0%
14														100%	13%	13%	0%
15															100%	14%	0%
16																100%	0%
17																	100%

CONCLUSIONS

This paper has reported on part of the outcomes of a substantial systematic review of academic knowledge on the topics of life cycle assessment of buildings and embodied carbon reduction in the built environment. We have chosen to develop the paper around the mitigation strategies identified in the existing literature as these might as well form very important directions for future research in the field. The seventeen mitigation strategies span across several disciplines and surely involve a plurality of stakeholders. As a consequence, the problem of EC does require a pluralistic solution because no single mitigation strategy is seen to be effective in EC reduction; this aspect should hopefully foster collaborative and interdisciplinary research even more in the future.

The analysis has also shown the interconnectedness of the role of the designer with those of the researchers, the materials manufacturers and the policy makers. For instance, the development and use of materials with low EC is intertwined with a better design which in turn is seen as the key element to also reduce, re-use and recover EC-intensive construction materials, such as steel and concrete. New tools, methods and methodologies are also needed to facilitate the transition to a low-carbon built environment, as are policies at both government and construction sector levels. These however require support from the society at large (social 'component') if a substantial change

is to be achieved. In developed countries, the upkeep of the existing building stock also stood out as a crucial element. In most cases, this was simply seen as the need to refurbish existing buildings although there are growing signs of more specific research activities in extending the building's life during a refurbishment project in a design-for-longevity aim.

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DELIVERING LONG-TERM BUILDING PERFORMANCE: A USER-CENTRED APPROACH

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ABSTRACT

In recent years the drive for the delivery of sustainable built environments has resulted in a focus on energy efficiency (regulated energy) in order to reduce CO_2 emissions and mitigate against climate change.

However, as regulated-energy is decreased the proportional importance of un-regulated energy (small power etc.), which is heavily influenced by occupants, is predicted to increase. In addition there is a body of evidence linking occupant health, wellbeing and productivity to both occupant behaviour and the building environment and it has been suggested that predicted climate change has the potential to impact further on comfort, energy use and the wider building environment.

In this context the short term focus on regulated energy efficiency, although not without merit, risks ignoring the influence of occupants and may impact upon occupant wellbeing, energy performance and ultimately long term building performance. Such a scenario could result in premature building obsolescence.

This paper, building on a body of research by the authors (and others) and supported by a review of the relevant literature, suggests that while consideration near term regulated energy remains important, this alone may not deliver long term performance. The paper presents a theoretical model of long-term building performance, highlighting the need to consider the impact of occupant behaviour on energy use, the impact of the building environment on occupant wellbeing and the potential impacts of climate change. The paper suggests that a user focused approach to design considering long term performance and an active approach to building management is required.

INTRODUCTION

The built environment is responsible for a significant proportion of global energy use and CO_2 emissions (U.S. Energy Information Administration, 2015), these emissions have in turn been linked to climate change (Intergovernmental Panel on Climate Change [IPCC], 2014). In this context there has in recent decades been a growing focus on delivering more energy efficient built environments.

To date this has been focused on regulated energy (heating, cooling and lighting), where a number of cost-effective savings can be realised. The implementation of increasingly stringent building regulations will reduce energy use in new buildings, while refurbishment programmes may help to reduce energy use in the existing stock. As regulated energy is further reduced (through regulations and refurbishment) it can be argued that the proportional importance of un-regulated energy (small power, desk level equipment etc.), which is influenced by occupant behaviour, may increase (Mulville et al., 2013). Furthermore, in addition to ambient environmental factors occupant behaviour has been shown to have a significant impact on occupant wellbeing (Haynes, 2007, Mulville et al., 2016).

It has been suggested that the movement towards air conditioned buildings and increasing levels of energy efficiency has resulted in negative impacts on occupants' health, wellbeing and productivity (Smith and Pitt, 2011). Increases in energy efficiency, particularly those focused on heat retention and air tightness may, in some cases, result in unintended consequences such as overheating linked to climate change (Mulville & Stravoravdis, 2016 and Jones et al., 2013), moisture issues and poor air quality (Al-Homoud, 2005).

Linked to these potential unintended consequences, it has been widely recognised that a significant building performance gap and particularly an energy performance gap exists (for a review see van Dronkelaar et al., 2016). Van Dronkelaar et al. (2016) links the performance gap to modelling uncertainty, occupant behaviour and poor operational practices and notes that complexity in design can lead to problems during construction which ultimately may impact upon building performance. These factors may be influenced by design stage assumptions about occupant behaviour, occupant decision making, occupant practices (as noted by Karjalainen, 2015) and the role of unregulated energy (Menezes et al., 2012). Arguably the performance gap may, over time, be further widened by the predicted impacts of climate change (Camilleri et al., 2001, Mulville & Stravoravdis, 2016 and Jones et al., 2013).

Figure 1 suggests how, based on the above issues, a performance gap may manifest itself over time. The 'optimum' line represents the performance that would be expected of a new building at any given point in time if it could be delivered instantaneously. The 'desired' performance line represents the performance owners/developers and occupiers/users would envisage based on returns on investment (developer), comfort (for wellbeing and productivity) and energy use (occupier). This is supported through periodic maintenance and refurbishment, as indicated by the light grey lines attached to the desired performance line. However, a gap emerges where the above issues are not addressed, as this gap grows the building may become increasingly obsolete.

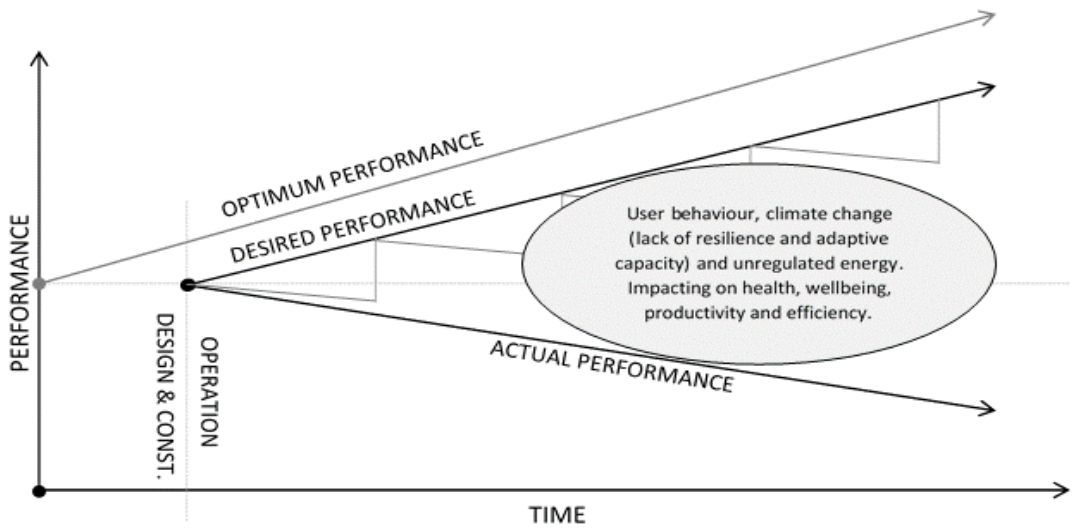

Figure 1. Long Term Building Performance Gap (Adapted from Jones et al., 2015)

The discussion that follows explores the issues noted in **Figure 1** in greater detail. It is argued that, in order to deliver a truly sustainable built environment, a focus on long term building performance beyond the 'point of handover', that considers the influence of occupant behaviour and the potential impacts of climate change is required.

LONG TERM BUILDING PERFORMANCE

The British Council of Offices [BCO] (BCO, 2015 in Sanderson & Edwards, 2016) defines building performance as:

> "the way that a building supports occupiers' differing aims and needs including driving quality and value, meeting sustainability objectives and providing environments that meet the needs of users, resulting in efficient and effective workplaces" (pg.32)

This multifaceted goal presents a number of challenges to both building designers and operators in delivering user centred buildings that are sustainable, efficient and effective. As noted by Cox et al. (2015) sustainability in the built environment largely refers to reducing the environmental impacts of buildings, as such, it may not be holistic sustainability but a relative term focused on particular aspects. Indeed, it has been argued (Voinov & Farley, 2007) that increased sustainability in one system or area may come at the cost of less sustainability in another. This discussion rings true in the built environment where there is often difficulty in finding the economic value of sustainability beyond immediate returns on cost (Keenan, 2015). In this context it can be argued that the sustainability debate in the built environment focuses largely on returns on energy savings. However, in many non-domestic buildings such as commercial offices, employee costs may significantly outweigh energy costs (CABE, 2005). The non-energy benefits or 'co-benefits' of user focused sustainable buildings may be more difficult to measure (such as better Indoor Environmental Quality [IEQ]). However, as noted by Sanderson and Edwards (2016) there is increasingly a move towards a customer centred approach to property management (reflected in the above definition) and as a result the recognition and perceived value of these 'co-benefits' may rise.

Adaptation and Resilience

As noted by Jones et al. (2013) there is a tendency to design and deliver buildings based around the needs of the 'here and now', however most buildings are developed on the assumption of a 60 year plus design life. In this context buildings must have a degree of resilience to and ability to adapt to economic, social and environmental change. Although efforts to mitigate the impacts of climate change have been increasing, often through increasingly ambitious energy performance targets, it is now widely accepted that a certain amount of climate change is inevitable (IPCC, 2007). In this context, in recent years, several research projects have explored the resilience of existing and recently constructed buildings to the impacts of predicted climate change (for example see Camilleri et al., 2001, Jones et. al., 2013 and Mulville and Stravoravdis, 2016). Cox et al. (2015) notes that a building's resilience is a measure of how well it continues to function after an event (and arguably during the event), while Bosher (2014), reviewing previous research, identifies four categories of resilience: 1) resistance, robustness and aspirations, 2) recovery "bouncing back", 3) planning, preparing and protecting and 4) adaptive capacity. In this context the ability of the building to adapt to change becomes a key aspect of resilience and therefore the overall sustainability of the building. Keenan (2015) argues that the sustainability of a building or system fits within the adaptive cycle of the building and that adaptation may be dependant on wider sustainability issues such as the availability of resources. Adaptation therefore could be viewed as, where resources are available, an opportunity to increase the resilience of the building. Where a building is unable to adapt or has limited resilience it may be at risk of premature obsolescence due to poor performance and such a building could be considered 'high risk' (Cox et al., 2015).

Climate Change and Building Performance

It can be argued that the sustainability aspects of the current regulatory framework in the built environment are largely (although not exclusively) focused on the mitigation of climate change. However, as noted above a certain amount of climate change may now be inevitable (IPCC, 2007) and the buildings we construct and refurbish today, must be capable of performing in or adapting to a changing climate (Mulville and Stravoravdis, 2016). That ability to adapt may be key to the buildings long term performance.

As noted, there is a growing body of research exploring the potential impacts of climate change on domestic and non-domestic buildings, which considers the potential impacts of a warming climate and more frequent extreme weather events. It has been argued that, although not without merit, the current drive to reduce energy use may risk optimising buildings in cool climates for heat retention and several studies have predicted an increasing overheating risk in such buildings (for example see Jones et al., 2013 and Mulville and Stravoravdis, 2016). Jones et al. (2013) in a study of a new educational building, note a number of potential climate change related impacts including a reduction in heating load and increased overheating risk overtime (with some overheating predicted as soon as the 2020s). Overheating has the potential to have significant impacts on occupant health and wellbeing (Mulville and Stravoravdis, 2016) with, in the non-domestic sector, corresponding impacts on productivity (Mulville et al., 2016). The wider impacts of climate change may include increased flood risk, which could impact on critical infrastructure, and more rapid materials degradation (Gething and Puckett, 2013).

As noted by Jones et al. (2013) and supported by Mulville and Stravoravdis (2016) adaptation planning and climate change risk assessments at the design stage, and possibly incorporated into the building regulations, may help to minimise the negative impacts of climate change on long term building performance.

Unregulated Energy

As regulations and other associated mechanisms drive down regulated energy (heating, cooling and lighting) the proportional importance of unregulated energy increases (Mulville et al, 2013). Menezes et al. (2012) suggests that a lack of understanding of unregulated energy is a contributory factor to the energy performance gap. Although small power items and other equipment associated with unregulated energy have increased in efficiency (and will likely continue to do so), the proliferation of devices means that small power is likely to remain an important factor in overall usage (Jenkins et al., 2009). In a study considering desk level energy use Mulville et al. (2013) found that up to 23% of energy used may occur outside normal working hours suggesting significant savings may be possible. Supporting this Kawamoto et al. (2003) found that in use utilisation of desk top equipment may be as low as 43%. Mulville et al (2013) found that savings of up to 20% at a desk level may be possible through monitoring, feedback and education. However, the same study suggests that to ensure the longevity of the savings, more constant monitoring and feedback may be required in order to reinforce the preferred behaviour.

Occupant Behaviour

As previously noted, it has been argued that building performance can be heavily influenced by occupant behaviour. Karjalainen (2015) notes, that there is a body of evidence that suggests occupants often do not understand the principles of how a building may function and as a result may use it in a non-optimal way. For instance, it has been noted that in the office environment artificial lights are often on despite the availability of natural light (Nicol, 2001). Where occupants realise their system understanding is poor they may be passive in their interactions with their environment (Karjalainen, 2015). Arguably as a consequence of this passive approach in commercial offices, much energy consumption may occur outside of working hours (Mulville et al., 2013). Karjalainen (2015) suggests that building designs that are less sensitive to user behaviour may result in significant energy savings. This less sensitive building design may be one where users have less to learn about the building, with more intuitive systems motivating users to save energy (Karjalainen, 2015). However, in such a scenario personal control should not be sacrificed (Karjalainen, 2015). Darby et al. (2016) suggest that a mixture of automatic and manual controls could both minimise energy consumption and maximise occupant wellbeing, by providing a high degree of personal control in an intelligent work environment.

There are several theories related to occupant behaviour both in the domestic and more recently, commercial office environment (for a review see Chatterton, 2011), what is clear from this work is that occupant behaviour is complex. Chatterton (2011) suggests that over time intentions and behaviour form habit and habit is difficult to change. Furthermore, Murtagh et al. (2013) note that self-reported pro-environmental behaviour may not always correlate to energy saving behaviour. Arguably, this could be linked back to the occupants' limitations in terms of understanding the intended function of the building.

Several studies (for example see Mulville et al. 2013 and Murtagh et al. 2013) have noted the potential for behaviour change campaigns supported by feedback, information and education to reduce energy use and potentially to encourage behaviour that is supportive of health, wellbeing and ultimately productivity (Mulville et al. 2016).

Health, Wellbeing and Productivity

Occupant behaviour and work patterns, the ambient environment and building configuration have all been linked to health, wellbeing and productivity in buildings (Mulville et al. 2016, Haynes 2007). Haynes (2007) suggests that the behavioural environment and occupant work patterns, including interaction and distraction, are important in terms of productivity in the workplace. This is supported by Mulville et al. (2016) who found that occupants who took less frequent breaks from their desk, and therefore have less interaction with co-workers, were more likely to experience headaches which may in turn impact upon productivity.

Singh et al. (2010) suggest that better IEQ, which is linked to better health and wellbeing, can lead to lower absenteeism rates. In support of this Bevan (2010) suggests that health and wellbeing improves productivity, while a lack of wellbeing may result in presenteeism (Hamar et al., 2015). Mulville et al. (2016) found that both the ambient environment and workplace behaviour have an impact on health, wellbeing and by extension productivity. That study found that where background noise levels were higher (in comparison to other areas) occupants were less satisfied with environmental conditions, despite air quality and temperature being more amenable than in other areas. This suggests that a hierarchy of environmental conditions may exist in relation to occupant satisfaction with noise being of particular importance. In turn, as previously noted (by Haynes, 2007) this can be linked back to interaction and distraction, thermal comfort and air quality however remain important factors (as noted by Callaghan et al., 2015 and Clements-Croome, 2013). Clements-Croome (2013) notes that improved IEQ can result in productivity gains of 4-10%, which given the importance of employee costs supports the case for a focus on occupant satisfaction.

Building configuration and, in the commercial office space, layout, can have a significant impact on employee satisfaction (Mulville et al. 2016). Open plan offices have been associated with increased levels of stress, a lack of perceived personal control, noise and disturbance (Bodin Danielsson, 2010; Pejtersen et al. 2011; Seddigh et al., 2015). Occupants of open plan offices may be more sensitive to background noise and may suffer from a lack of privacy although some benefits may remain (Van der Voordt, 2004). Levels of perceived personal control (which in some layouts may be minimal) can have an impact on overall satisfaction (Lee and Brand, 2005) and it has been suggested that enhanced, possibly desk level, user controls may be of benefit (O'Neill, 2008) in the workplace.

As suggested by Haynes (2008) and supported by Mulville et al. (2016) an active approach to workplace management may help building managers to understand the impact of the building environment on occupiers and to adjust accordingly. Such an approach could, through the provision of feedback and information, also incorporate behaviour change campaigns to reduce energy use and encourage behaviour in support of health, wellbeing and productivity.

DELIVERING LONG TERM BUILDING PERFORMANCE

Based on the preceding discussion, if a sustainable built environment that provides long term performance is to be provided, building design and operation must take a user focused approach that delivers health, wellbeing, efficiency, resilience and adaptive capacity. This requires whole of life thinking in terms of building performance. **Figure 2** sets out how such an approach could be delivered with, at the design stage, user centered design to support the preferred/desired behaviours and risk based adaptation planning to consider the potential impacts of climate change. This is then supported at the operational stage by an active approach to building management incorporating feedback, information and education to reinforce the design intention to occupants and provide building managers with guidance on the key issues to address or adapt to as required. The discussion that follows expands upon these suggestions.

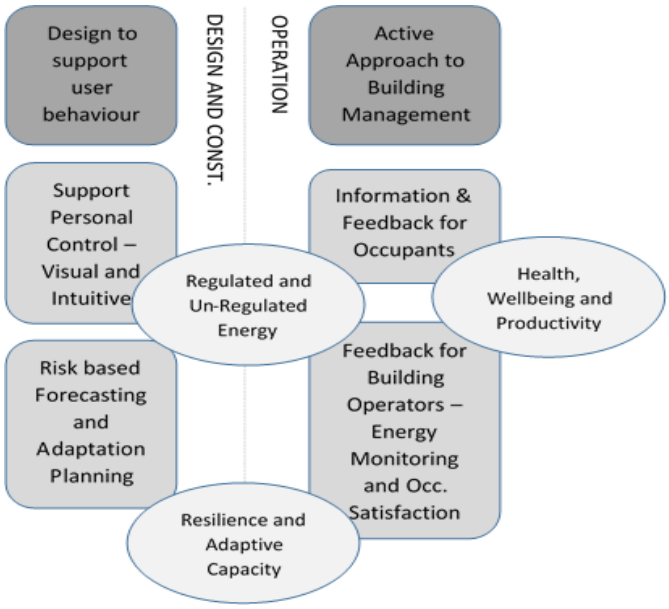

Figure 2. Model of Building Performance

User Centred Design

As suggested by Karjalainen (2015) building designs that are less sensitive to occupant behaviour may offer benefits, especially where more realistic views of occupant behaviour can be taken into account and the building itself is supportive of the preferred behaviour. As noted by Delmas and Lessem (2014) users will not devote much time to learning how the building works. Therefore, less behaviour sensitive designs should include for intuitive controls systems that also take into account the users reactionary as opposed to anticipatory approach to interaction with building systems (Leaman, 1999 in Karjalainen, 2015). This could be in the form of systems that suggest or recommend to users when and how action should be taken, thus providing users with feedback and education and supporting the active approach to workplace management as suggested below. Although fully automated controls may offer benefits in terms of energy consumption they could reduce the perception of personal control which is an important factor in occupant satisfaction, thus highlighting the importance of a user centered approach. As a result, in a building with wider automation the need for personal control would remain, this could be in the form of enhanced local or desk level controls which have been shown to be of benefit (O'Neill, 2008). At the design stage such an approach would require careful consideration of how users are likely to interact with building control systems, this could be informed by input from facilities managers and potential occupants or lessons learnt from the post occupancy evaluations. A requirement for mandatory post occupancy evaluations, implemented through building regulations or environmental assessments to help inform such decisions could be of benefit. Such a user centered approach may help to reduce the performance gap associated with both regulated and un-regulated energy use while improving occupants' satisfaction and productivity.

Risk Based Adaptation Planning

In the context of climate change it has been suggested (Jones et al. 2015) that adaptation planning (incorporating backcasting and forecasting) at the design stage may allow for realistic and cost effective strategies to be developed that take account of the level of risk associated with the predicted impacts. Jones et al. (2013) in a study of a new educational building, in conjunction with the project design team, facilitated the development of a range of potential adaptations, including technical (the use of modular boilers, increased duct sizes for additional cooling capacity etc.), managerial and behavioural adaptions (changes to operational schedules and dress codes) which were then evaluated within a risk framework. This allowed for a number of adaptations to be either implemented during the construction phase or planned in advance and where necessary enabling works conducted to ensure future adaptations could be implemented on a cost effective basis. It has been suggested (Mulville and Stravoravdis, 2016) that a similar approach (all be it that study was discussing domestic buildings) could be incorporated into the regulatory framework through regulations that take a 'forecasting' and risk based approach to climate change, while Camilleri et al. (2001) suggest the use of a climate change sustainability index to identify vulnerable buildings. Such an approach (implemented via the building regulations) could provide users or potential users with a greater understanding of the building's resilience prior to purchase or occupation, much in the same way that Display/ Energy Performance Certificates [DECs/ EPCs] provide comparative information. This approach to adaptation planning could help ensure the building has resilience and adaptive capacity which in turn may improve or maintain energy efficiency and user satisfaction over time.

Active Approach to Building Management

For the operational phase, as suggested by Haynes (2008) and supported by Mulville et al. (2016), an active approach to workplace management may be required to support the organisation and the user. Such an active approach could incorporate measures to encourage energy saving behaviour (such as those noted by Mulville et al., 2013) and behaviours that enhance health, wellbeing and productivity (as noted by Mulville et al. 2016) while providing more detailed building specific performance metrics.

Several studies have demonstrated that behaviour change campaigns can be successful in reducing energy consumption (for example see; Mulville et al., 2013 and Murtagh et al., 2013). While it has also been suggested that similar campaigns could be used to improve occupant health and wellbeing by altering workplace patterns (Mulville et al., 2016). Such campaigns utilise monitoring, feedback and goal setting, education and information, using social norms and competition to encourage the preferred behaviour. An active approach to building management, utilising such measures, should incorporate a continuous feedback loop (Darby et al., 2016) to reinforce the preferred behaviour among occupants and inform building managers of issues arising. As noted by Darby et al. (2016), such continuous reinforcement may be required to ensure that any observed benefit associated with a change in behaviour is not just a short term phenomenon and may, over time, become habitual. This active approach to workplace management could allow, as suggested by Sanderson and Edwards (2016), property managers and occupiers to work together in maximising building performance. The approach suggested could also increase the availability of performance metrics related to the building and help capture user satisfaction which could in turn be made available to potential tenants (as suggested by Sanderson and Edwards, 2016).

These metrics could be incorporated into 'performance leases', which as noted by Janda et al. (2016) have seen increasing use in certain sectors, or, as previously suggested could be incorporated into an alternative versions of a DECs that focus on building performance metrics and risks. In support of this Sanderson and Edwards (2016) suggest that occupiers place greater emphasis on quality over cost when defining building performance and that finding ways to enhance occupiers' business profitability could be of greater importance than cost savings. The approach outlined here, where tied to performance leases or DECs, may help in emphasising the presence of quality (or otherwise) in the workplace while providing greater information for decision making.

DISCUSSION & CONCLUSION

User centred design and an active approach to building management could help to reduce the building performance gap. Considerations of the potential impacts of climate change, through climate impact risk assessments may increase resilience and adaptive capacity and combined, these approaches may help to deliver long term building performance. This could be supported by the use of a climate change index and user satisfaction surveys with performance leasing and an alternative approach to DECs to increase the availability of comparative building performance information.

For building designers, while regulated energy use will remain important, the approach proposed would require a refocusing on the building user. This may present a number of challenges as user behaviour is not commonly considered in depth during the design process beyond a number of predetermined assumptions. It may be that the incorporation of facilities managers into the design stage or mandatory requirements for post occupant evaluations (to provide feedback) may enable designers to deliver such user focused buildings. Where adaptation planning (for climate change) is to be incorporated, the presence of potential users and facilities managers will help to ensure that realistic adaptation proposals can be developed. During the operational stage building owners and property managers may need to take a more active and less reactive approach to delivering building performance. This would require ongoing monitoring, feedback, information and evaluation linked to user satisfaction. More widely ensuring preferred behaviours (to reduce energy use and improve productivity) may require a change of workplace culture so it is seen throughout all levels of the organisation.

At a regulatory level, climate change risk assessment and adaption planning may need to be considered in order to ensure resilience over time, especially where (in the case of commercial offices) most development may be speculative and focus on short term returns. Greater availability of occupant satisfaction and performance in use data may help to increase the use of performance leasing. Such data, in conjunction with climate change risk data, could be made available as part of an alternative or revised approach to DECs.

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COMPARING SEVERAL EXPERIMENTAL (DYNAMIC) CO-HEATING PROTOCOLS TO IDENTIFY THE THERMAL PERFORMANCE OF RESIDENTIAL BUILDINGS

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Keywords: on-site co-heating tests (static/transient/dynamic), thermal performance, protocols comparison, protocols applications

ABSTRACT

Co-heating tests have been used by many researchers for the characterisation of the heat loss coefficient (HLC) of building envelopes. Traditionally, practitioners have to collect several weeks of continuous measurements under representative, but not extreme, weather conditions to derive regression lines with acceptable correlation coefficients between the daily means of the measured variables. This (quasi-)static type of experimental protocol underlies that the building remains in steady-state conditions day after day during the test, and implies that no dynamic model nor predictions may be derivable as part of the test results. These 3 weaknesses were the reasons for the investigation of other (dynamic) experimental protocols that combine a thermal solicitation together with the appropriate data analysis method. Next to (quasi-)static protocols two main options are possible which we distinguish as transient or dynamic protocols.

In this study we compare the state-of-the-art (quasi-)static protocol, with the transient protocol plus 3 other (new) dynamic protocols. It is shown that, when executed in appropriate conditions, all protocols yield similar results and that a dynamic protocol is hence preferable because of its more general applicability (easier to meet the constraints, shorter test, more detailed results). The advantages and drawbacks of each test protocol are eventually put in parallel with the variety of objectives the test is expected to reach in order to sketch prospective trends and recommendations depending on practical applications.

In order to be able to accurately compare the various experimental protocols, special attention has been paid to parameters that are usually not included in the analysis, such as the measurement of the exfiltration rate, which significantly contributes to the global HLC when the building is not sufficiently air-tight compared to its insulation level. This paper does not explain how data sets have been collected since previous papers have already given details on that issue.

INTRODUCTION

On-site measurement campaigns and data analysis require in-depth and balanced skills regarding the test environment, the experimental procedure and the data analysis. The Heat Loss Coefficient (HLC in W/K) expresses the heating power that is lost by transmission and ventilation through a building envelope under a temperature gradient of 1K. Steady-state thermal conditions and energy balance are required to derive this "static" parameter. Assuming these conditions are met during the test is not trivial and requires at least daily averaging of the acquired data. Moreover producing representative regression lines requires accumulating data from long measurements. Eventually, the obtained results are static parameters that are only usable to characterise the building in steady-state conditions, never observed in real weather conditions and occupancy patterns, while dynamic models will in turn more and more be necessary in a context of energy demand side management within smart grids and peak load reduction. In order to address (part of) the above-sketched weaknesses, several (dynamic) experimental protocols have been developed. These combine a thermal solicitation together with the appropriate data analysis method. Next to (quasi-)static protocols two main options are possible which we distinguish as transient or dynamic protocols, plus operational testing.

The measurement may happen quickly if the main time constant of the system under investigation is small enough. This is typically the case for lightweight and moderately insulated buildings. A protocol has recently been investigated by an insulating material manufacturer and promoted under the name Quick U Building [1]. Such a protocol is initially designed with the assumption that a single exponential response of the indoor temperature will be retrieved from a pure heating power step, the reason for which we label it here transient as opposed to static and dynamic. Depending on the main time constant of the building under investigation, this method can be applied during just one night or requires two consecutive nights. The solar aperture is evidently not part of the results.

Typical co-heating tests (thermostatically-controlled temperature set-point inside the building) on the contrary last for about 2 weeks, due to varying weather conditions and the inertia of building envelopes. Resampling of the data (heating power, temperature gradient and solar radiation) into daily-averages enables applying linear regressions from which model parameters are extracted. The duration of these tests represents a clear drawback since the building cannot be used while under test (intrusive infrastructure). The thermal inertia is evidently not part of the results.

Intermediately, short dynamic tests have recently been investigated. Typically, ROLBS (Randomly-Ordered Logarithmic Binary Sequences) and PRBS (Pseudo-Random Binary Sequences) heating power solicitations are used covering about 10 days. Other dynamic tests such as multi-sine (X-sine) sequences have recently been studied and optimized [2]. The latter have shown interesting characteristics in terms of the validation of the identified dynamic models. While being relatively short, all of these tests allow identifying at least two more parameters on top of the heat loss coefficient: the thermal inertia (or associated time constant) and the solar aperture.

Further, even shorter dynamic tests (5 days) have been designed, implemented and investigated, such as the hybrid test [3], or the sine-sign-sweep (3S) test [4]. The hybrid test combines characteristics of thermostatic control, step down and up, and multi-sine power control segments smoothly assembled in order to achieve optimal de-correlation of the acquired data (time series of the model variables), which are all useful characteristics during the identification process. The 3S test

aims at the same objectives as the hybrid test, but with less complexity in the test design since it is solely controlled in power. It is based on a sine function (smooth curve), deformed in order to show a shape approximating crenels (guaranteeing a better signal/noise ratio as in PRBS tests), to sweep through frequencies of interest (targeting medium and higher time constants of the building) and with one cycle aligned with the first day (providing relatively steady temperature conditions during that day, selected to be sunny) which is helping the identification of the solar aperture. The written form and the parameter tuning of the 3S function are detailed in [4].

Finally, another method could be based on smart energy sensors, integrated in the building and its systems before commissioning, that make long-term monitoring possible (since not intrusive). In this integrated test the distribution and emission efficiency of the heating system are evaluated together with the building envelope, giving a closer image of the building efficiency as a whole. If the building is in use during the test, it is called operational testing and further correction of the acquired data is required before analysis in order to cope with specific occupants' behaviour. This approach was recently studied [5, 6] and requires additional investigations concerning the accuracy of the results, even for unoccupied buildings.

In this paper, we will compare 5 different tests, one belonging to the "transient" category, three to the "dynamic" category (PRBS, multi-sine and hybrid tests) and the last one to the "static" category. The operational test and the 3S test described above are not part of the study.

Each test "package" is associated with practical advantages and drawbacks to be put in parallel with what is required from the test. In the prospective of this paper, we assume that an accurate dynamic representation of the building is required. Nevertheless, this should not hide other characteristics of the test protocol such as the cost, etc. Each application will require adequate balance between the characteristics in order to determine the best-suited approach to follow.

OBJECTIVES AND STRUCTURE OF THIS STUDY

We first (section 4) present the modelling and data analysis procedures used in this paper, according the notations of the EN ISO 13789 standard. We then (section 5) review the performed experiments, and we explain how the data sets were acquired and how qualitative they are. We subsequently (section 6) compare the results obtained from the various protocols and qualitatively compare these protocols. We finally (section 7) draw short conclusions to the attention of practitioners.

MODELLING AND DATA ANALYSIS PROCEDURES

Various procedures from the very simple towards the much more complex are already developed [1, 7, 8]. Each procedure is intuitively best paired with a specific experimental data set. For example, daily averages of dynamic data sets are inadequate for applying linear regressions. Reversely, a dynamic analysis is not suited to static data sets since such sets don't emphasize well the dynamic characteristics of the building.

Dynamic analysis

The preferred analysis methods are parameter identification methods applied on dynamic data sets. In this paper, a grey-box stochastic 1D-model is used to represent the entire building. It is rather simple and often appears suitable:

$$dT_i = \frac{(T_e - T_i)}{R_{ie}C_i}dt + \frac{Q_h}{C_i}dt + \frac{A_w q_s}{C_i}dt - \frac{Q_v}{C_i}dt + \sigma_i d\omega_i \quad (1)$$

$$dT_e = \frac{(T_i - T_e)}{R_{ie}C_e}dt + \frac{(T_a - T_e)}{R_{ea}C_e}dt + \sigma_e d\omega_e \quad (2)$$

$$HLC \cong \frac{1}{R_{ie}+R_{ea}} + \frac{Q_v}{T_i - T_a} \quad (3)$$

$$\text{where} \quad Q_v = 0.33nV(T_i - T_a) \quad (4)$$

where T_i, T_e and T_a are respectively the indoor air, the building envelope and the ambient (outdoor air) temperatures, R_{ie} is the thermal resistance between the interior and the building envelope, R_{ea} is the thermal resistance between the building envelope and the interior thermal medium, C_i and C_e are the heat capacities of the interior (internal walls) and of the building envelope (external walls), Q_h is the energy flux from the heating system, $A_w q_s$ is the solar aperture multiplied by the energy flux density from the solar radiation (i.e. solar gains) , Q_v is the energy flux from the ex-filtrations, ω_i and ω_e are standard Wiener processes, and σ_i and σ_e are their incremental variances. Finally, n is the air change rate estimated by direct measurement, V is the volume of the building, and *0.33* is the volumetric heat capacity of the air expressed in Wh/m³K. Note that stochastic models make use of Wiener processes in order to cope with imperfections of the chosen model structure and with the noise included in the collected datasets that are both unavoidable and have to be accepted as the right balance with respect to useless or even problematic test and model complexity.

The corresponding equivalent RC-network is represented in Figure 1 :

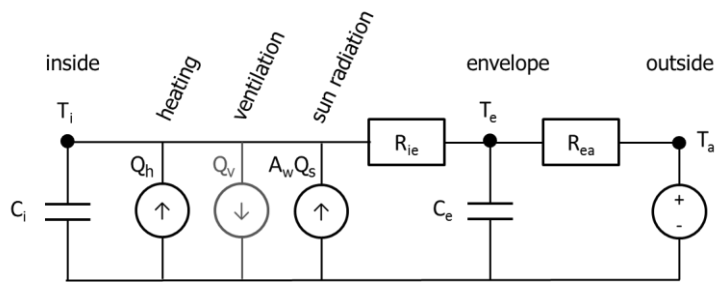

Figure 1: Equivalent RC-network of the whole building envelope thermal model

The interior temperature is the output state of the model and is associated with a thermal capacity (air & furniture). The outdoor temperature is chosen as input. The (unobservable) building fabric envelope temperature is assumed to be aggregated in one single node and is obviously associated with a thermal capacity. The overall thermal resistance offered by the envelope against the heat losses is represented by two thermal resistances in series. Finally, the system is subjected to three other inputs: the electric heating power, the ventilation losses and the solar radiation, all predominantly acting on the inside air node temperature.

Removing the envelope state and neglecting ventilation losses (Q_v could also be hidden in a corrected Q_h term) would combine equations (1) and (2) into equation (5) only:

$$dT_i = \frac{(T_a - T_i)}{R_{ia}C_i}dt + \frac{Q_h}{C_i}dt + \frac{A_w q_s}{C_i}dt + \sigma_i d\omega_i \quad (5)$$

Transient analysis

The transient method is typically applied on nightly data sets obtained from steps in the heating power (see Figure 8). This method has been shown to give reasonably accurate results under certain conditions. The measurement must be performed when there is no solar radiation (at night), and with good steadiness in T_a and Q_h such that equation (5) becomes:

$$\alpha \triangleq \frac{dT_i}{dt} \cong \frac{d\Delta T}{dt} = \frac{-(\Delta T)}{RC} + \frac{Q}{C} \quad (6)$$

This relation can be duplicated for two periods with significantly different values of Q (index *h* and *c* here below stand for heating and cooling sequentially) and the resulting set of 2 equations with 2 unknowns yields the following expressions for HLC and C:

$$C = \frac{Q_h \Delta T_c - Q_c \Delta T_h}{\alpha_h \Delta T_c - \alpha_c \Delta T_h} \quad \text{and} \quad HLC = \frac{1}{R} = \frac{\alpha_h Q_c - \alpha_c Q_h}{\alpha_h \Delta T_c - \alpha_c \Delta T_h} \quad (7)$$

As explained in the introduction, the two measurements follow each other in one single night if the weather conditions are propitious and if the main time constant of the building is small enough (limited thermal resistance and mass) to produce clear and clean temperature ramps.

Static analysis

The most basic analysis is associated to the state-of-the-art co-heating experiments assuming quasi-steady state conditions and is obtained by further simplification of equation (5) for which T_i is supposed invariable. When then can rewrite:

$$C_i \frac{dT_i}{dt} = 0 = \frac{(T_a - T_i)}{R_{ia}} + Q_h + A_w q_s \quad (8)$$

$$\text{or} \quad HLC - \frac{A_w q_s}{\Delta T} = \frac{Q_h}{\Delta T} \quad (9)$$

$$\text{where} \quad HLC = \frac{1}{R_{ia}} \quad \text{and} \quad \Delta T = T_i - T_a \quad (10) \text{ and } (11)$$

In equation (9), both the HLC and $A_w q_s$ terms are found implicitly from a bi-linear regression using daily-averaged data points.

It is finally also possible to correct the used energy term by the ventilation losses if one requires estimating the building UA-value (H_D according to ISO 13789) instead of the overall heat loss coefficient HLC. Equation (9) can then be modified as:

$$UA - \frac{A_w q_s}{\Delta T} = \frac{Q_h - Q_v}{\Delta T} \quad (12)$$

This correction is used in order to better compare the experimental designs and analysis methods since the actual air change rate could strongly vary in time and hence impact the HLC. Further in this paper we will refer to building HLC and building UA-value, depending if the correction is applied or not.

QUALITATIVE EXPERIMENTS AND DATA SETS ACQUIRED

Qualitative experiments

One purpose of this study is to show how adapted dynamic co-heating tests[4] could more advantageously (exhaustively, accurately, robustly, rapidly) identify the dynamic characteristics of a building envelope model thanks to their specificity [9] such as exciting the system with a broad dynamic content in order to emphasize the various time constants of the system, to reduce the measurement time, and avoiding high peaks in the residuals between the measured and predicted outputs of the identified model, thanks to the smooth characteristics of the data, which makes statistical analysis and validation easier and unbiased.

Next to this, the developed experimental infrastructure was also able to maintain homogeneous temperatures, especially during power control tests like the multi-sine test, and even during sunny days, thanks to an adaptive spread of the power in the different zones of the building, using pulse-width modulation on the individual relays that control the electric heaters.

Finally, in order to focus the analysis on the transmission part of the heat loss coefficient, which was the part of interest and supposed to be replicable across experiments whatever the weather/wind conditions, the contribution of the exfiltration part of it (obtained by multiplying the air change rate by the temperature gradient) has been continuously monitored thanks to tracer gases controlled by a multi-channel Bruël & Kjær unit, following a constant concentration scheme.

Descriptions of the design of thermal test sequences and of the infrastructure assembled to implement them were firstly given in [3]. We describe here several aspects of it but not exhaustively.

The infrastructure of the experiments consists of “kits” installed in each zone and connected to the central control & acquisition unit. The communication between the main unit and the kits happens via a serial port (see Figure 2).

Figure 2: Electric fan, heater, decentralized module

4 The term « co-heating » is used here in the broadest sense and is not limited to measurements under steady (thermostatically-controlled) indoor temperature.

The decentralized modules are responsible for controlling the heaters (pulse-width modulation), measuring the power of both the air mixing fan and heaters, and measuring the temperature of the zone. The communication happens continuously with instructions updated every 100 seconds. If the required power in a zone is e.g. half the installed nominal power in that zone, it will be on during half the cycle time. Several corrections are applied to account for the presence of the air mixing fan (constant power), for the non-linearity's of the heaters, the potential drift in time of the nominal power, etc. A robust system is implemented through a hybrid closed-loop/open-loop control system.

Other modules are used to monitor the outdoor environmental conditions, among others. All the boxes are eventually connected to the central control and acquisition node. A software user interface (Figure 3) is developed so that experiments can be parameterized, started or even adjusted, and that all running variables can be monitored remotely.

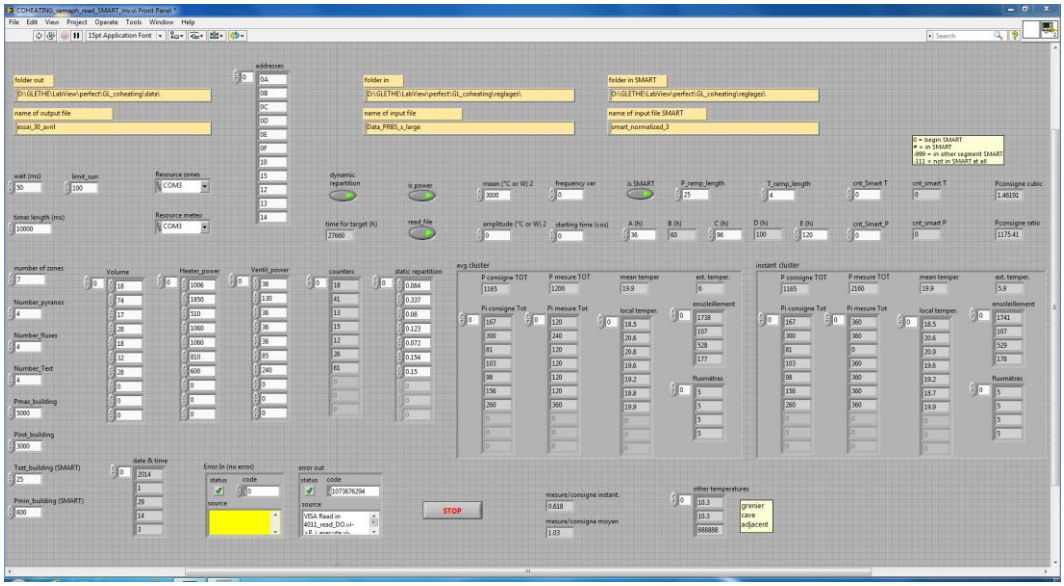

Figure 3: Front panel (user interface) of the NI LabView control & acquisition program

The developed infrastructure merely allows for dynamic and smooth heating sequences such as X-sines signals but it also significantly improved the temperature homogeneity within the building.

In the example illustrated in Figure 4, the total targeted heating power is spread among the 7 zones of the measured building. The graph shows a complete (clear sky and sunny) day from midnight to midnight, where the daytime has a white background and night time a light blue one.

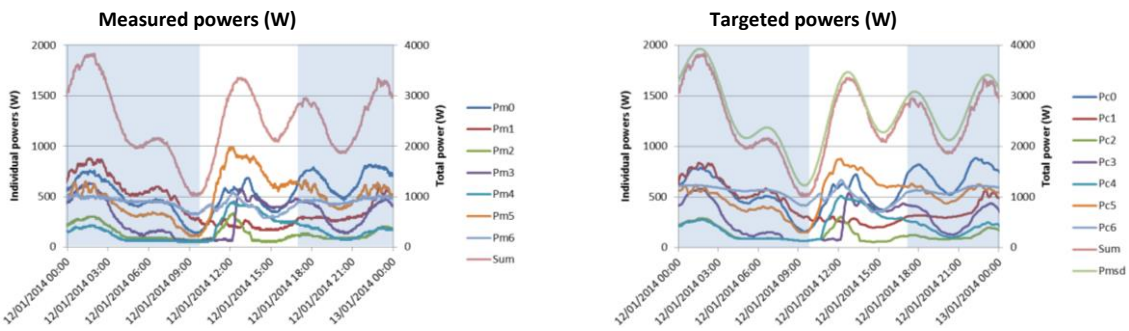

Figure 4: Heating power adaptive spread under dynamic measurement and correspondence between target (on the right) and measured (on the left) individual and global power

We first see on the right graph a good superposition of the total measured power (in pink) with the total target power (in light green) that varies between 1000W and 4000W (right scale). Individual powers (left scale) are distributed adaptively in order to maintain a homogeneous temperature in the building. The zone n°1 (Pm1, in red) is the largest of the house and logically requires a relatively high heating power during the night, especially because of the large glazing. Nevertheless, these are oriented to the South. Hence almost no power is required in that zone during sunny days because of large solar gains. A major part of the remaining heating power is hence self adaptively directed to zone 5 (Pm5, in orange), a mid-size room oriented to the North-West which does not receive solar gains.

In Figure 5 and Figure 6, the evolution of the individual room's temperature during two consecutive days can be seen. In Figure 5 the adaptive power spread function and the air circulation fans are turned off at the end of the morning of the first day. The circulation fans (only) are turned back on at the end of the morning of the second day. In Figure 6 the adaptive power spread function and the air circulation fans are always turned on.

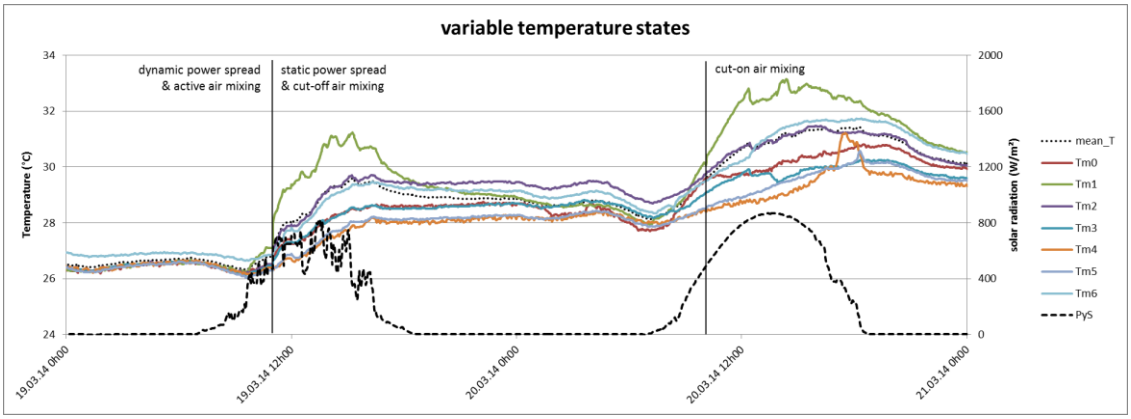

Figure 5: Temperature spread in the building under static distribution of heating power when doorframe fans are cut-off (centre) and after their reactivation (right)

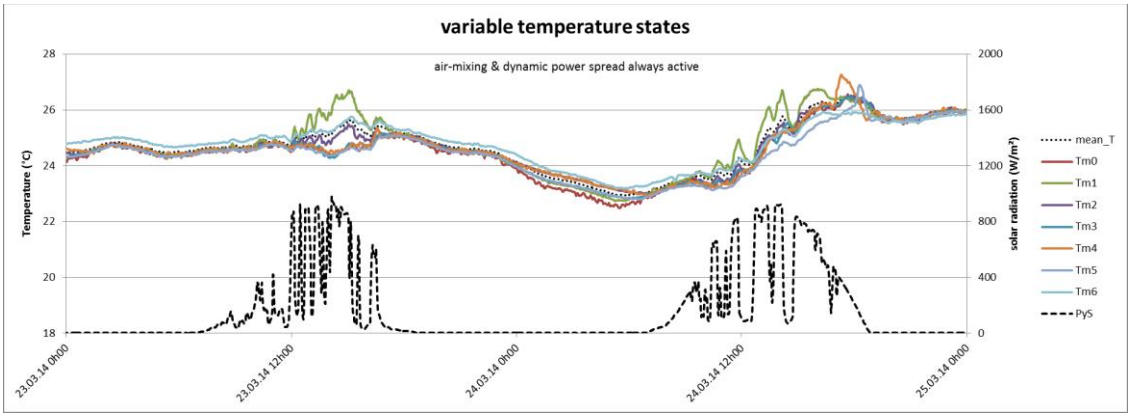

Figure 6: Temperature spread in the building under dynamic distribution of heating power with doorframe fans always activated

It can clearly be seen by comparing both figures that the second experience yields more homogeneous temperatures. It can also be found from the first experience that circulation fans (including fans placed at doorframes) are much less effective in reaching homogeneous temperatures than the adaptive power spread.

Note that temperature heterogeneities then sometimes reached up to 4K between rooms, while the gradient between the "average" indoor and the outdoor environment was around 16K. In case such conditions persist during the test, the accuracy of the aggregated indoor temperature can be questioned as well as the accuracy of the identified heat loss coefficient to which errors could propagate. The amount of deviation in the results due to that issue has not well been quantified and requires one-to-one comparable data sets, either obtained through tests in laboratory conditions or through simulation. We nevertheless have proposed a global index to characterize temperature heterogeneities [3] and suggest limiting them as much as possible.

The building on which the experiments were implemented (see Figure 7) is a detached house located on a small hill (Lat. 50°41' N, Long. 4°31' E, at BBRI facilities) and exposed to the winds with ventilated attic and cellar. The effective internal surface area is 86m² and the ground floor height is 2.55m, the internal volume being 220m³. The external dimensions are 8.2m by 13.12m. The exterior walls are cavity walls insulated with 10cm of mineral wool. The ceiling is made from wooden rafters insulated with mineral wool. The floor is made from concreted and is weakly insulated. The living room is oriented SSW and is heavily glazed. The windows are equipped with double glazing and wooden frames.

Figure 7: General outside view of the building and inside view of a room

The U-values of the envelope components are expected to be about 0.38, 1.30, 0.21 and 0.39 W/m²K respectively for the vertical walls and windows, for the roof and for the floor. This leads to an overall UA-value (H_D according to ISO 13789) of about 110W/K. Thermal bridges are estimated to be about 40W/K such that the transmission loss coefficient reaches 150W/K. It is important to note that this value is not extremely precise since several design parameters are unknown and the building is already 30 years old.

The ventilation system is sealed during the measurements. The air tightness of the building is 4.3 h^{-1} under 50 Pa. The standard ventilation loss coefficient hence reaches 21 W/K ($0.34\ V\ n_{50}/15$), which is 14% of the reference transmission loss coefficient, and which leads to an overall heat loss

coefficient of about 170 W/K. The true heat loss coefficient of course depends on the actual rate of air change (and temperature gradient), which is continuously measured during the experiments as explained earlier.

Data sets acquired

The acquired data sets, illustrated in Figure 8, are a temperature set-point (Co-heating), a (smoothed) PRBS test sequence, a multi-sine (X-sines) test sequence, the hybrid (SMART) test and the transient (QUB) test.

For all sets, 5min sample time data files are available. Outdoor climate sensors installed on or near the building include air temperature and relative humidity, wind speed and direction, vertical global solar radiation on the East, South and West façades, as well as horizontal global and diffuse solar radiation. Individual building zone temperatures are aggregated into a unique temperature.

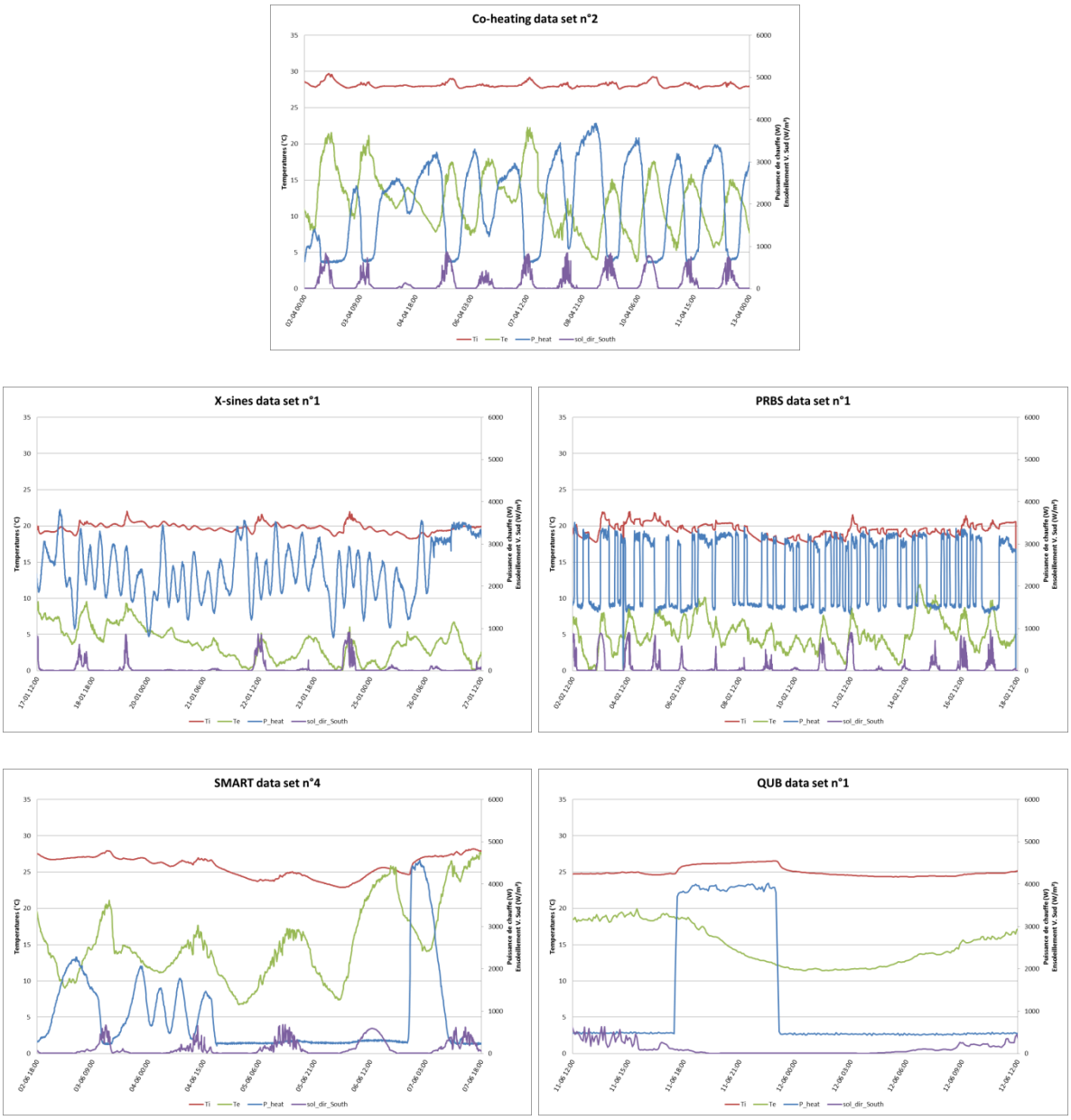

Figure 8: Various measurement data sets. Temperature set-point co-heating (top), smoothed PRBS and X-sines (center), hybrid and transient (bottom)

A unique variable has also been obtained from multi-zone measurements for the air change rate. The latter is illustrated in Figure 9, showing center moving 4h and 24 averages of the crude data relative to a hundred days of measurements in total.

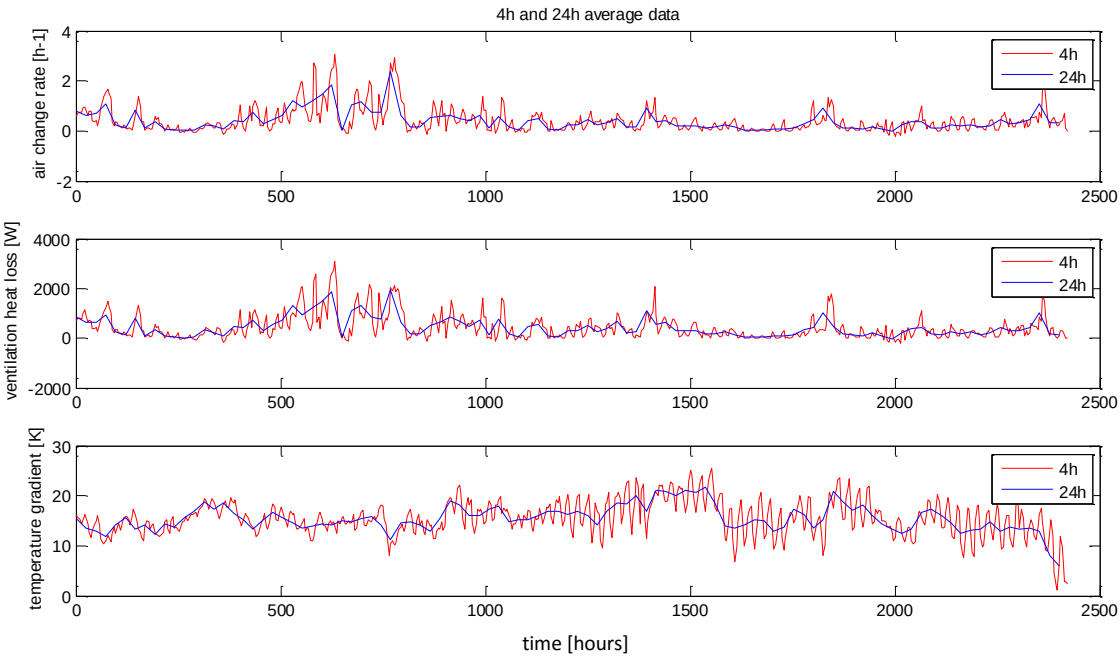

Figure 9: measurement of air change rate (top), temperature gradient between the indoor and ambience (bottom), and calculated ventilation heat loss (middle)

It can be seen that, even based on daily averages, the heat losses associated to the exfiltrations (called here the ventilation heat losses) are varying over the time. While the standard air change rate is $0.3h^{-1}$ for our building, the actual one, based on the 4h averages varies between 0 and $3.1h^{-1}$, and the global average value is $0.4h^{-1}$, which correspond to 29W/K or 17% of the total heat loss coefficient. Notably, ventilation losses during periods with strongest infiltrations/winds are of the same order of magnitude that there are only transmission losses and can hence propagate errors towards the identified heat loss coefficient if not correctly accounted for.

Additionally data related to the measurement of the U-values and Λ-values (surface temperatures and density of heat flow) of three wall components (floor on cellar, external walls and ceiling under attic) are also available. Although these are not further developed here, we briefly note that results obtained in accordance to the WD/ISO 9869-1 standard are consistent with the expected characteristics given above and that standard deviation of results from the 5 experiments are small.

COMPARISON OF EXPERIMENTAL PROTOCOLS AND RESULTS

Introduction

Summarizing the previous sections, the 5 data sets acquired (especially the ones relative to the dynamic tests) have the following characteristics: broad dynamic content, not stiff but smooth data series, homogeneous temperatures, correction capability from ventilation losses, and of course correction capability from solar gains.

The objectivation of the first three characteristics and their interest can be found above and in the bibliography and no focus will be further put on them specifically. Sub-sections 6.2 to 6.5 all give insight of the impact of including (when applicable) or neglecting the last two characteristics. The individual and combined impacts of solar gains (due to solar radiation) and ventilation losses (due to exfiltrations and wind) on the accuracy of the identified Heat Loss Coefficient can be the most easily visualized on static co-heating tests and are especially covered in sub-section 6.2.

Section 6.5 eventually and qualitatively compares the various protocols presented with regard to technical (a.o. accuracy) and practical aspects.

Static test results using static (& dynamic) analysis method

Figure 10 left shows 4 linear regressions obtained from two types of data and from two consecutive co-heating tests on the same building. Figure 10 right similarly shows 4 bi-linear regressions obtained from the same data, where the solar gains have been accounted for. Each time (linear and bi-linear regressions), two coefficients represent the total HLC estimation, and two others represent the transmission loss part of the HLC only (named UA), where the ventilation loss part has been removed.

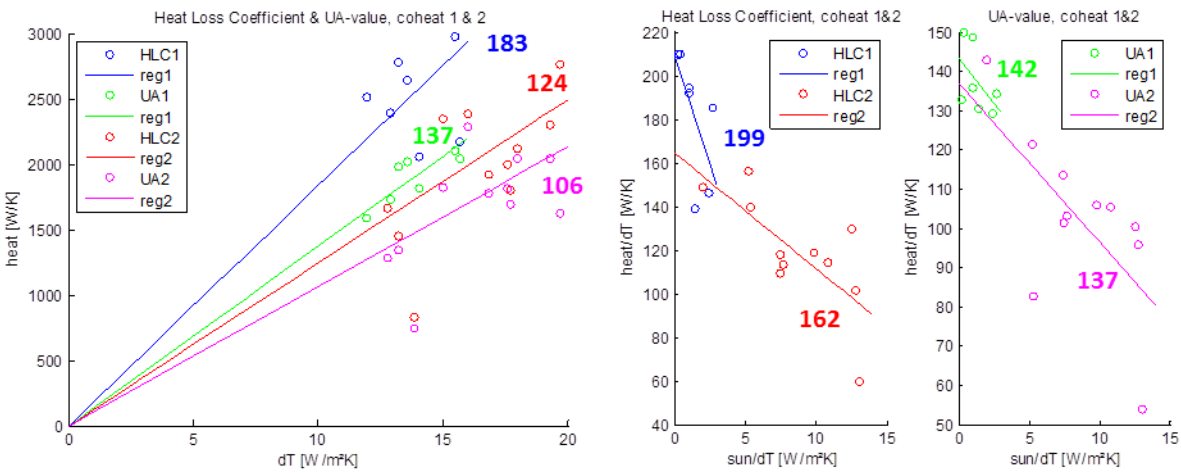

Figure 10: repeated static co-heating test using various data analysis methods

The same data is displayed in Table 1, where we also have added the results from a dynamic analysis method.

Table 1: Results of static (& dynamic) analysis on static data sets

	Parameter	**Co-heating 1**			**Co-heating 2**		
		Linear	Bi-linear	Dynamic	Linear	Bi-linear	Dynamic
HLC	A_w (m²)	-	13.3	2.0	-	5.4	4.2
	Losses (W/K)	183	199	175.5	124	162	160
UA	A_w (m²)	-	3.7	2.5	-	4.4	5.1
	Losses (W/K)	137	142	143	106	137	152

Bi-linear regressions are known to yield more trustable and higher estimations of HLC than linear regressions, because compensation of transmission losses by solar gains over a complete day are not allowed anymore. The increase of the estimates is respectively 16 and 38W/K for the first and second experiments. We can do the same exercise on the UA estimates that respectively increase by 5 and 31W/K. Note also that the discrepancy between the two UA estimates based on linear regressions is 31W/K.

We can now look only at the bi-linear regressions and compare the variability of the estimates in function of the chosen indicator. The gap between the two HLC estimates is 37W/K, while the gap between the two UA estimates is only 5W/K. Moreover, the gaps relative to the identified solar apertures are respectively 7.9m² and 0.7m².

From these observations, we can deduce that, in this case at least, neglecting the ventilation losses has an impact that is as important (37W/K) as the one of neglecting the solar gains (31W/K). Neglecting the ventilation losses in parallel strongly contributed to a distorted identification of the solar aperture.

In general, we suggest that both approximations might have the same level of impact, even for modern buildings, since the increase of the air tightness went along with the increase of the thermal insulation, and that at least some knowledge should be collected on a daily basis about the air change rate during the experiment.

Results obtained from the dynamic analysis method (see columns 3 and 6 of Table 1) are consistent with bi-linear regressions and show UA estimates that are closer to the expected value of 150 W/K than with static analysis of the same data. This is only used as a sanity-check since combining a dynamic analysis and a (quasi-)static data set is not recommended.

In the continuation of this paper, we both give HLC and UA estimates, although our main purpose is here to compare the UA estimates from the various test protocols (static, transient dynamic).

Transient test results using transient (& dynamic) analysis method

The transient analysis is here applied to the QUB data sets. Note that selected overnight extracts of PRBS tests can potentially serve as transient tests. Table 2 shows both results from the specific analysis method and from the more general dynamic analysis method, applied on 3 different tests, at both the HLC and UA levels.

Table 2: Results of transient & dynamic analysis on transient data sets

	Parameter	**QUB 4**		**QUB 2**		**QUB 3**	
		transient	dynamic	transient	dynamic	transient	dynamic
HLC	A_w (m²)	-	-	-	-	-	-
	Losses (W/K)	193	145	142	153	160	145
UA	A_w (m²)	-	-	-	-	-	-
	Losses (W/K)	191	144	140	150	158	144

Here, the solar gains are neglected since the measurement starts at sunset. The transient analysis protocol gives HLC estimates between 142 and 193 W/K while the dynamic analysis approach gives estimates between a narrower band (145 to 153 W/K). UA estimates are very close to HLC estimates because the air change rate was very small for these data sets.

It is noticeable that the dynamic analysis method gives more reproducible results than the transient analysis method. The dynamic method is indeed more reliable since it does not require making any of the hypotheses made in section 4.2 (steady heating power and weather conditions / ambient temperature during the test). Despite the shortness of the data sets UA estimates obtained with the dynamic method have here been found relatively reproducible and are located in a narrow band of 146 W/K ± 7 W/K.

Some additional testing that is not displayed here nevertheless let us think it is important to consider with caution a test that started after a very sunny day, or that runs under special or extreme weather conditions, especially if the dynamic analysis method is not used.

Note that a simple transposition of the transient test/analysis (in W/K) onto the building components (in W/m²K) is not possible since the heat flow density across the walls do not meet the method's assumptions. All other dataset types (static and more specifically dynamic) presented in this paper are instead usable to obtain U-values and Λ-values estimates, as explained in section 5.2.

Dynamic analysis

In this section, next to the thermostatically-controlled quasi-static co-heating and the transient data set, we analyse the results obtained on the 3 last types of data sets: the (smoothed) PRBS data set, the X-sines data set and the hybrid data set. Compared to classic co-heating data set, these are increasingly richer and shorter.

Analysis has been done on 15min sample time data each time. The solar aperture, the heat losses and thermal capacity of the envelope are given both at the HLC and the UA levels. We also give the preliminary average air change rate and solar radiation during the test (first two lines of the Table 3). At last we show the difference between HLC and UA estimates (bottom of Table 3) and the mean and standard deviations (right of Table 3). In this table, we've selected the second co-heating test (because the weather was then sunnier) and the first QUB test (from 3 similar tests).

We first see that the mean of the HLC and UA estimates are 160 and 148 W/K. These are very close to the expected values of 170 and 150W/K respectively. The mean difference between HLC and UA is only 12W/K (lower than expected). This mean seems acceptable, but actually hides much bigger numbers, such as 40W/K for the PRBS test case, where there is a higher air change rate. The differences HLC-UA appear realistic for the co-heating and the X-sines sets (identified HLC's are 160 and 158 W/K respectively) while it is less understandable for the Hybrid set (probably because of underestimated HLC estimates: 143 W/K only).

Looking at the right column, we see a very good reproducibility for UA estimates, much better than for the HLC estimates. We also see that working at the UA level instead of the HLC level has an impact on the solar aperture estimates (they are bigger at the UA level).

Table 3: Results of dynamic analysis on various data sets

	15min sampling	**Static**	**Transient**	**Dynamic**			**All together**	
		Coheating	**QUB**	**PRBS**	**X-sines**	**Hybrid**	**mean**	**stdev**
	Air change rate (h^{-1})	0.26	0.17	0.92	0.27	0.37	0.40	0.30
	Solar radiat° (W/m²)	139	-	74	48	113	94	40.4
HLC	A_w (m²)	4.2	-	4.3	5.9	3.0	4.4	1.19
	Losses (W/K)	160	153	184	158	143	**160**	**15.1**
	Inertia (Wh/K)	11053	6981	6438	9715	13580	9553	2950
UA	A_w (m²)	5.1	-	6.2	8.0	5.4	6.2	1.30
	Losses (W/K)	152	150	144	151	144	**148**	**3.9**
	Inertia (Wh/K)	16035	7068	8669	12473	13235	11496	3612
HLC-UA	Losses (W/K)	8	3	40	7	-1		

Concerning the thermal inertia, the highest values are found with co-heating tests and the lowest with PRBS tests. This is somewhat logical since PRBS tests (even smoothed) are the most stiff and dynamic tests and do not give the time to the envelope to accumulate thermal energy, while co-heating tests are the loosest ones from that perspective. This observation shows that thermal inertia is in fact not an intrinsic parameter but depends on the solicitation applied to the system and could vary between zero and an upper bound. The thermal solicitation should hence be designed such that it is 'similar enough' to the solicitation the building is facing when in operation, if one plans to use

the identified dynamic model to control the building in operation. Although not displayed here, it should be noted that the thermal inertia identified with the QUB tests are quite scattered and not replicable. The thermal inertia remains anyway a difficult parameter to determine univocally in general.

Discussion

From the experiments and only looking at the UA level of the analysis (recall: this implies a sufficient knowledge of the exfiltrations), it is difficult to conclude if there is one test that is the most reliable, precise and/or robust.

Static tests and analysis might slightly underestimate the UA value and solar aperture because of the averaging across one complete day possibly hiding a tiny annihilation of transmission losses and solar gains in the regressions. Very long tests might give an advantage on the replication side but are costly and hence not generalizable in the practice.

Transient tests reversely are very short, and can give a good first insight into the UA value especially if the data is analysed dynamically. We nevertheless think it is important to consider with caution tests that started after a very sunny day, or that run under special weather conditions, especially if the data is not analysed dynamically.

From the pure perspective of parameter identification, other dynamic tests are all valid, whatever their duration provided that enough representative dynamics are captured, and with a preference for tests that deliver smooth enough time series. From other perspectives (easyness, cost, duration, etc.) the 3S test and the operational test briefly described in section 2 might prove particularly advantageous. This requires nevertheless further investigations.

It is clear from the presented study that all protocols allow identifying a Heat Loss Coefficient (HLC), or better said a UA-value, which is the major purpose of the co-heating tests. Table 4 displays indicators that further specify the way this value is obtained (together with additional results if applicable). These indicators are the easiness (is it easy to design, assemble, install and dismantle the test infrastructure?), the cost (how expensive is the test infrastructure and how skilled is the practitioner required to be to acquire/analyse the data appropriately?), the duration/occupancy (is the test short or can the building be occupied during the test?), the robustness (are the results replicable in various conditions?), and the accuracy (is the risk for bias under control?).

Two indicators specify whether extra parameters are obtained and how qualitatively. These are the thermal mass (are one or several parameters identified?) and the solar aperture (is a mathematical or a physical parameter identified?).

Finally, there are three sub-level indicators that relate to the robustness and the accuracy: are the temperatures spatially homogeneous during the test? Are the acquired data well decorrelated? And are they smooth enough to avoid peaks in the residuals from the identification process?

The values in Table 4 have to be understood as scores associated with the indicator. For example, a high value in the cost indicator of a protocol means the protocol is advantageous (i.e. cheap) respectively to that indicator. It is important to note that Table 4 is based on general experience in

conducting test protocols, larger than what can be displayed in the scope of this paper. It should not be understood as the outcome of a sound consensus in the scientific community but rather as a personal summary of experiences and a first proposition to the community towards further refinements.

Note that Table 4 assumes that the air change rate is always measured during the experiment, the same way whatever the selected protocol and therefore cannot be used as comparative indicator.

	« static »	« transient »	« dynamic »			« operational »
	Set-point	**QUB**	**PRBS**	**X-sines**	**Hybrid/3S**	**In-use**
Easyness	4	4	3	2	2/3	5
« Cost »	3	4	2	2	3/3.5	4
Duration/occupancy	1	5	3	3	4	4
Thermal inertia	3	3	4	4	4	3
Solar gains	3	0	4	4	4	3
Robustness	3.5	3	4	4	4	3
Accuracy	3	2.5	3.5	4	4	2.5
T° homogeneity	2	3.5	2	3.5	3.5	2
Decorrelation	NA	NA	4	4	4	?
Residual peaks	NA	NA	2	4	3.5	?
« Overall score »	2.9	3.1	3.4	3.3	3.6/3.8	3.6

Table 4: qualitative comparison of test protocols w.r.t technical and non-technical indicators with scores ranging from 0 (bad) until 5 (good)

It can for example be seen from Table 4 that the transient test tends to be easy and cheap but that it is not very robust/accurate nor the most informative (no solar aperture, weak thermal inertia). Oppositely, the dynamic hybrid test looks more complex and costly but provides informative and qualitative results. According to Table 4 again, the static co-heating test is not expected to perform better than the operational test, except maybe on robustness and accuracy although this is not based on sound experimentations.

The overall score given in the last line of Table 4 is based on the average of the first 7 lines (that include 3 “feasibility” indicators followed by 4 “quality” indicators), and consequently tends to favour the protocols giving the most qualitative/informative results.

Next to the exfiltration heat losses, we have shown that other parameters played an important role in results weaknesses. If the temperature is not homogeneous enough in the building, the “average” indoor temperature cannot be known with precision (especially during sunny days), hence the same with the temperature gradient and finally the HLC or UA value. If measurements occur during or shortly after exposure of the building to significant solar radiation, and if the solar gains are not identified correctly or not at all, the final results will be wrong. Finally, we can drive the same conclusions if the accumulation of thermal energy in the building shell during the test is not accounted for.

Assuming these 3 conditions (homogeneous temperatures, identified solar gains and thermal inertia) and high quality results are required, the most interesting strategies are dynamic testing in empty

buildings, more particularly the 3S test (mainly because of the good quality indicators) and operational testing (mainly because of the good feasibility indicators).

In case solar gains and thermal inertia are not essential for the application, then the transient test with a dynamic analysis scheme seems an attractive candidate, provided the weather conditions are propitious during the test. Additionally, if the building is known to be very airtight and if no significant wind is observed during the timespan of the (advantageously short) test, the measurement of exfiltration can become optional and the test hence becomes even easier and cheaper.

Therefore, operational testing (because of the good feasibility and despite the difficulty to measure exfiltration a.o.) and the transient test (because of the feasibility and the possibility to drop the measurement of exfiltration) would be the best candidates for large scale applications (e.g. for labelling), while dynamic testing such as the 3S test remain the best candidates for specific applications (including construction companies' best practices refinement or predictive control for intelligent-flexible buildings).

CONCLUSIONS

To reliably determine the main parameters of a building model or building component the test environment, but also the experimental procedure and data analysis should be treated with care. If these prerequisites are met, the heat loss coefficient and more specifically the transmission losses or UA-value can be consistently estimated with various methods.

The choice of the methodology will depend on the desired usage of the results. At the building level, static analysis only gives the UA-value and some indication on the solar aperture. Transient analysis gives some (but imperfect) insights about the thermal capacity and no indication on the solar aperture. Dynamic analysis enables the most correct identification of both thermal capacity and solar aperture, with extra levels of details as shown in [4] or [7]. Additionally it could serve to predict the building behaviour and to better understand it.

In order to produce highly reliable and informative results, high quality and specific data are required: data series should have a broad dynamic content and be smooth enough (yet with a good signal/noise ratio), temperatures should be spatially homogeneous, ventilation losses and solar gains should both be accounted for (i.e. identified).

Eventually, depending on the field of application, the right balance between feasibility and quality characteristics of the methods has to be determined by practitioners. For large scale applications such as labelling, operational testing (less intrusive) and the transient test (faster) are well-positioned candidates. For more specific applications (research, development, intelligent buildings) and if more detailed or higher quality results are required, dynamic testing remains essential.

ACKNOWLEDGMENT

This paper is based on data and knowledge obtained in 2014, in the context of a pre-normative research project supported by the Belgian Bureau for Standardization (NBN). We would like to thank this support as well as the support received from various members active in the Annex 58 of the International Energy Agency and from the Leeds Sustainability Institute - Leeds Beckett University.

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Circular Economy/ Green IT

SYSTEMATIC LITERATURE REVIEW OF USING KNOWLEDGE MANAGEMENT SYSTEMS AND PROCESSES IN GREEN ICT AND ICT FOR GREENING

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Keywords: Knowledge Management, Green ICT, Sustainability, Tacit and Explicit Knowledge.

ABSTRACT

Knowledge management (KM) is considered to be one of the key players essential for improvement and achievement of performance excellence. KM systems accumulate data and information in order to provide better opportunities in a journey towards sustainability in the knowledge economy. The present research conducts a systematic literature review on the application of KM systems and processes to the field of green ICT and ICT for greening. The standard systematic literature review method was used in order to employ a manual search of journals and conference proceedings. More than 40 articles and book chapters were chosen for in-depth analysis, which shows increasing interest in the application of KM to sustainable development. The review covers essential knowledge management tools and technologies identified within the body of literature and provides a summary of their implication to sustainable development. The paper illustrates that, KM systems are essential in order to foster Green ICT and ICT for greening. This study concludes by proposing suggestions for future research.

INTRODUCTION

Our world is facing complex challenges including climate change, water, air, and soil pollution, resource depletion. Those problems require urgent attention. Therefore, environmental protection and green energy became top priorities in many countries, and various principles of sustainable development have been integrated into national policies and programs (Australian Government, 2010; METI, 2008; Ministry of Science, Technology, and Innovation of Denmark, 2008; Suryawanshi et al., 2013).

One of the most widely adopted definitions of sustainability is so-called "Brundtland definition", which was given by the World Commission on Environment and Development (1987). According to it, sustainability means "development that meets the needs of the present without compromising the ability of future generations to meet their needs".

One of the providers of better opportunities in a journey towards sustainability in the knowledge economy is knowledge management (KM). It is a "trans-disciplinary approach to improving organisational outcomes and learning, through maximising the use of knowledge. It involves the design, implementation and review of social and technological activities and processes to improve the creating, sharing, and applying or using of knowledge" (Australian Standard AS 5037-2005).

Knowledge could be tacit and explicit (Nonaka and Takeuchi, 1995). "Explicit knowledge typically refers to knowledge that has been expressed into words and numbers. Such knowledge can be shared formally and systematically in the form of data, specifications, manuals, drawings, audio and videotapes, computer programs, patents, and the like" (Becerra-Fernandez, 2010). "Tacit knowledge includes insights, intuitions, and hunches. It is difficult to express and formalize, and therefore difficult to share." (Becerra-Fernandez, 2010). Managing both tacit and explicit knowledge is the challenge of KM.

The KM concept was introduced in the beginning of 1990. Since then, knowledge has been considered as the key of a sustainable competitive advantage in the new economy and an essential player for the improvement and achievement of performance excellence (Roblek et al., 2014). Therefore, many scientists tried to evaluate the importance of KM for sustainable development and assess its impact on the subject. According to Wong (2010), "KM and sustainable development has been coined for slightly more than decade now, as an essential solution to the global crisis". Results of the empirical assessment of KM application to sustainability (Mohamed et al., 2009) showed that KM is very important for innovation and sustainable development, especially for efficient use of resources. The same author mentioned that information and communication technology (ICT) is a very effective tool for knowledge mobilization in such a knowledge intensive field as sustainable development. Furthermore, Faucheux and Nicolaï (2011) claimed that ICT has the same influence on the knowledge economy as electricity had on the industrial revolution.

The article focuses on investigation of the potential contribution of KM to green ICT and ICT for greening. The paper is organised as follows. In the next section, relationships between KM, ICT and sustainability are described. The section entitled "research method" provides the methodology of selection, extraction and analysis of the literature. Research results provides an analysis of the body of literature, summary of the papers, description of knowledge management tools, and examples of using KM tools and technologies for green ICT and ICT for greening.

SUSTAINABILITY, KM AND ICT: RELATIONSHIPS BETWEEN THREE ASPECTS

Relations between KM, ICT and sustainable development can exist in different combinations and proportions. Figure 1, which was adapted from Mohamed et al. (2009) with modifications, shows possible combinations.

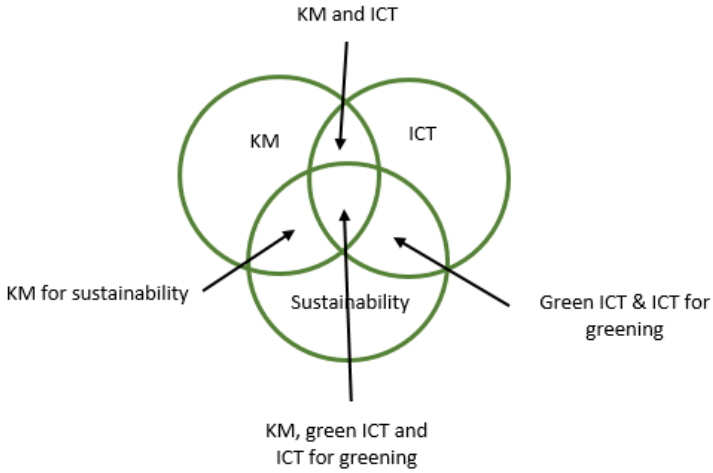

Figure 1. Relations between KM, ICT and sustainability.
Source: Adapted from Mohamed et al., 2009

KM and ICT

More than twenty years ago Davenport & Prusak (1998) spoke about incorporation of ICT practices into KM "as a combination of the capabilities of technology and the generic features of KM, for example considering the Internet as a knowledge repository". Today ICT plays a vital role for implementation of KM applications (Becerra-Fernandez, 2010), by supporting processes of knowledge discovering, sharing, capturing an application within the organisations. Even though social aspects of organizations, such as communities of practice (CoP), are also important, web-based technologies, artificial intelligence, expert-based and decision-support systems, object oriented and relational databases, semantic networks, etc. continue to transform the field of KM. Garsia-Alvarez (2014), who presented analysis of effects of ICT in KM and innovation, emphasized importance of ICT for both tacit and explicit knowledge. It is obvious that use of cutting-age ICT enables significant improvement in KM.

KM for sustainability

As well known, sustainable development consists of three components: ecological, social, and economical. Presented research is mostly concentrated on the ecological component, in particular, on the connections between KM and sustainable ICT. The description of "sustainable ICT" will be given later. However, it is worth mentioning that a large number of papers are dedicated to influence of knowledge management to economical and social aspects of sustainable development (Wong, 2010; Halawi et al., 2005; McNeil, 2011; Roblek, 2014, etc.). These papers emphasize the role of KM for organizational change and development of sustainable competitive advantages. KM systems and practices improve core business competencies and organizational commitment, foster innovation

development, and contribute to decision-making processes (Davenport and Prusak, 1998). McNeil (2011) also emphasized increases in opportunities for innovation and operational excellence while presenting KM benefits for the business, for the community, and for the individual.

Green ICT and ICT for greening

Since the 2000s, ICT has become an essential player in the journey toward a low carbon economy. The Smart 2020 report (The climate group, 2008) recommended the intensive deployment of ICT both for enhancing the monitoring of the environment and human activities (in industry, building, transport, etc.) and for distributing smart ICT systems to mitigate pollution, waste, food quality and supply problems, energy constraints, etc. Certain conceptual frameworks have been developed for the classification of ICT effects on the environment and sustainability (Hilty and Lohmann, 2013).

Murugesan (2008) defined "Green IT" as "the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems […] efficiently and effectively with minimal or no impact on the environment." Other definitions are "the using of IT resources in an energy-efficient and cost-effective manner" (Bose and Luo, 2011) and "an initiative to encourage individuals, groups, and organisations engaged in the use of ICT to consider environmental problems and find solutions to them" (Chai-Arayalert and Nakata, 2011). Green ICT includes such areas as green software development; data centre design, layout, and location; power management; server virtualization; recycling, green metrics, etc. (Murugesan, 2008).
The term "Green ICT" should be distinguished from the term "ICT for greening", or "greening by ICT". Indeed, green ICT is concerned with how to make ICT goods and services more sustainable over their whole life cycle, mainly by reducing the energy and material flows they invoke (Hilty and Lohmann, 2013), whereas ICT for greening describes how ICT can be used to make other sectors more environmental friendly.

There are numerous papers, which study KM and ICT (e.g. Butler and Murphi, 2007; Jain, 2014; Nguyen and Burgess, 2014), KM for sustainability (e.g. Halawi et al., 2005; McNeil, 2011; Roblek et al., 2014; Wong, 2010), ICT and sustainability (e.g. Hilty and Lohmann, 2013, Osseyran, 2013; Rondeau et al., 2015). However, there is a lack of literature, which examines the relationship between all three concepts.

RESEARCH METHOD

In the study, the systematic literature review methodology was applied for data selection, extraction, analysis and syntheses (Silvius and Schipper, 2014; Tranfield et al., 2003).

The main objective of that review is to offer researchers a comprehensive review of previous papers related to applying KM to green ICT and greening by ICT.

The process of data selection includes a systematic periodic search for articles related to sustainability and knowledge management. As a search engine the following databases were used: Science Direct, Emerald, and Scopus databases. The following journals were also explored: ACM Transactions of Knowledge Discovery from Data, Data Mining and Knowledge Discovery, IEEE Transactions of Knowledge and Data Engineering, Journal of Cleaner Production, Knowledge and

Information Systems, Knowledge Management for Development, Knowledge-Based Systems Journal, Knowledge and Process management.

For the research the following key words were used: “knowledge management” and “knowledge” along with “green ICT”, “sustainability”, “greening by ICT”.

In this research were considered only articles published in peer-reviewed journals for the period of twelve years, starting from 2005. Books, book chapters and conference proceedings were also included.

Based on the abstracts, those papers were excluded from the selection, which contained information about societal sustainability or concentrated only on green ICT and ICT for greening. Published papers, which contained information only on sustainability or sustainability and ICT, regardless of knowledge management were also excluded.

In order to retrieve the full publications for the research, Science Direct was used. The final sample of the study consists of 41 papers.

RESEARCH RESULTS

Table 1 gives a list the 41 publications sampled for this study. The information includes the following: type of the sector (green ICT or ICT for greening), aim of the paper, type of ICT tool or technology to support sustainability.

Table 1. Summary of the papers

№	Authors (year)	Type of the sector	Aim of the paper	ICT tool or technology
1	Abdullah et al. (2015)	Green software development (GSD)	To assesses literature on GSD in regards to the evolution of green computing, and discusses how KM comes in to assist in managing the knowledge of GSD	warehouse
2	Ali and Avdic (2015)	Sustainable rural development	To provide a framework for knowledge management in sustainable rural development, and an inventory of existing frameworks for that	Internet/ intranet web portal
3	Awasthi et al. (2011)	Sustainable transport	To present a multi-criteria decision making approach (MDMA) for selecting sustainability transportation systems under uncertainty	MDMA; Fuzzy TOPSIS
4	Belkadi et al. (2015)	Sustainable manufacturing	To explore the capabilities of knowledge based frameworks combined to PLM approaches as a backbone for supporting resources optimization	Global KB-PLM framework

5	Cash et al. (2003)	Environmental monitoring	To develop a framework for understanding the effectiveness of systems that link knowledge to action for sustainability	Not clear
6	Cinar and Kayakutlu (2010)	Energy sector	To propose a decision model that will support the researchers in forecasting and scenario analysis fields	Bayesian Network (BN) models
7	Dong and Hussain (2011)	Healthcare	Framework for a semantic service matchmaker that takes into account the ambiguous, heterogeneous nature of service information in Digital Health Ecosystems	Semantic service matchmaking (Semantic Health Service Search Engine)
8	Dorasamy et al. (2013)	Disasters management	Systematic review of papers pertaining to the application of knowledge-driven systems in support of emergency management	knowledge-based emergency management information systems (EMIS)
9	Fan et al. (2015)	Green buildings	To present a time series data mining methodology for temporal knowledge discovery in big building automation system data	Data mining
10	Ferreira and Pernici (2013)	Green Datacenters	To explore the characteristics of knowledge based agents to discover energy saving opportunities within these dynamic systems	Service-based Applications
11	Gamarra et al. (2016)	Sustainable manufacturing	To review technical literature and introduce an innovative approach to microgrid planning	Data mining
12	Hercheui (2011)	Green buildings	To show the relevance of designing Green ICT solutions, which cope with tacit and explicit knowledge, and reduce the complexity in managing information on sustainability	Internet tool
13	Howland et al. (2015)	Natural resource management	Design of strategies for farmer engagement in the knowledge-sharing online platform of the AES-CE (Acronym in Spanish for Sharing Experiences for Site Specific Agriculture)	Knowledge-sharing online platform

14	Kivits and Furneaux (2013)	Sustainable construction	To outline the benefits, enablers, and barriers associated with BIM and makes suggestions about how these issues may be addressed	Building Information Modeling
15	Kontopoulos (2016)	Green buildings	To present an ontology-driven decision support system for facilitating the selection of domestic solar hot water systems	Ontology-based decision support tool
16	Linger et al. (2013)	Natural resource management	Describes an action-oriented TbKM framework aimed at building capability for policy work in order to address the challenges of a complex policy environment	task-based KM (TbKM) framework
17	Li et al. (2013)	Energy sector	To determine the appropriate spread parameter in using the GRNN for power load forecasting	generalized regression neural network
18	Liu et al. (2016)	Sustainable transport	To improve utilization efficiency of public transportation services, according to people's real demand for public transportation	Not clear
19	Liu et al. (2010)	Disaster management	To contribute a reference in decision making for prevention of grassland fire disaster and for stockbreeding sustainable development planning	GIS and information diffusion-based methodology
20	Lwoga (2011)	agricultural indigenous	To present application of KM approaches for the management of IK and its integration with other knowledge systems for agricultural development in developing countries, including Tanzania	Not clear
21	Majewski et al. (2014)	Green ICT	To present a literature review and theoretical investigation combining the areas of Business Process Simulation (BPS) and Knowledge Management (KM)	Not clear
22	Majchrzak et al. (2011)	Healthcare	To present a business rules-based decision support system for the allocation of traumatized patients	Decision support system
23	Mohamed et al. (2009)	KM for sustainability	Empirically assess the importance of KM to sustainable development	Not clear
24	Mohamed et al. (2010)	ICT, KM and sustainability	To quantitatively evaluate the importance of ICTs for sustainable development	knowledge-oriented ICT infrastructure

25	Morik et al. (2012)	data mining for sustainability	To present data mining techniques that explore and analyze environmental spatio-temporal data and help operate better sustainable systems	Data mining
26	Nilashi et al. (2005)	Green buildings	Performance assessment tool that analyzes the effect of factors in developing the sustainable building	Knowledge-based expert system: fuzzy inferences system and green buildings rating system
27	Pietrosemoli and Monroy (2013)	Sustainable construction	To present references about the positive relationship existing among KM, sustainable construction and the global sustainability goals	Lessons-learned systems
28	Pinto et al. (2015)	Electricity market	To complement the ALBidS strategies by combining them and taking advantage of their different perspectives through the use of the “six thinking hats” group decision technique	Adaptive Learning strategic Bidding System: Decision support system
29	Reed et al. (2011)	Sustainable land management	To present a hybrid methodological framework	Not clear
30	Shaheen et al. (2011)	Energy development	To provide method for classifying a nation’s hydrocarbon development into one of five classes: futuristic; conforming; sustainable; unsustainable; critical	Data mining
31	Shaluf and Ahamadun (2006)	Disaster management	To provide with background on the technological emergencies, expert system, and technological emergencies expert system development	Expert system (decision support)
32	Shelbourne et al. (2006)	Sustainable construction	To describe the development of the C-SanD tool and supporting web portal implementation, evaluation and take-up in the project’s industry partners	Process Protocol method Web-portal
33	Smirnov et al. (2011)	Disaster management	To propose an approach to emergency situation response that benefits from the ubiquitous computing	Decision support system

34	Srivastava (2011)	Sustainable transport	To present an anomaly detection method based on Virtual Sensors to help detect overconsumption of fuel in aircraft	Virtual sensors (anomaly detection method)
35	Stojanova et al. (2012)	Disaster management	To build predictive models of estimating the risk of fire outbreaks in Slovenia by using state-of-the-art data mining techniques	Data mining, decision-making system
36	Tan et al. (2012)	Sustainable construction	To understand and describe the types of sustainability knowledge of importance to CPO organizations	Web-based KMS
37	Togawa et al. (2016)	Energy circulation systems	To introduce an innovative information network system integrating a regional geographical information system and ICT application and evaluate its performance and future outlooks	Innovative information network system
38	Trotta (2010)	Sustainable product development	To analyze important tools used by PLM to formalize knowledge for sustainable new products development	centralized interfacing for complex databases; integrated platforms
39	Venters et al. (2005)	Sustainable construction	To introduce SSM as a method for conceptualizing the industry's knowledge environment and increasing sustainability in construction industry practice	Soft-system methodology (SSM)
40	Vikhorev et al. (2013)	Manufacturing	Framework for energy monitoring and management in the factory	Decision support system
41	Xu et al. (2013)	Green building	To consider a bi-level multi-objective benefit trade-off problem between a green building developer and a contractor under a fuzzy environment	interactive fuzzy programming technique

Figure 2 presents results of distribution publications by the field of technology. As it is stated, only 7% of the sample dedicated for implementation of KM to green ICT. Majewski G. et al. (2014) described a combination of KM with business process simulation and its influence in green ICT. Two other publications are dedicated to green software development (Abdullah et al. 2015) and green datacenters (Ferreira and Pernici, 2013), where an integrated mechanism to identify energy saving opportunities within data centers was presented.

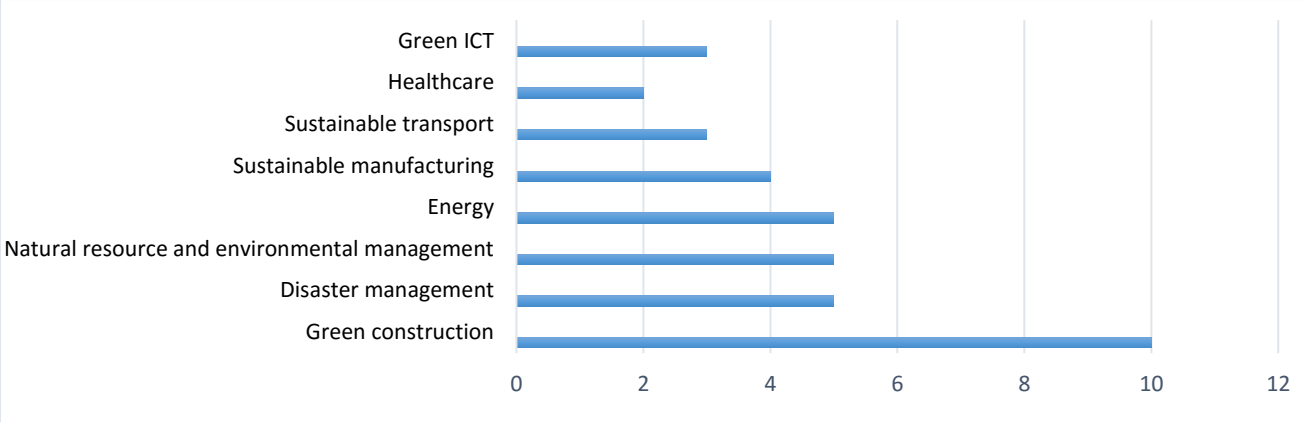

Figure 2. Distribution of ICT for greening

Below key KM applications to ICT for greening are presented.

Green Constructions

The majority of papers from the sample (24%) are dedicated to the use of KM and ICT in green constructions. The U.S. Environmental Protection Agency defines green construction as "the practice of creating structures and the using of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition" (https://www3.epa.gov/). Green constructions include efficient use of energy and water, protection of the occupant health, reduce in waste, pollution and environmental degradation.

The fact, that the amount of papers dedicated to green constructions is so high, does not surprise. The building sector is considered as one of the major consumers of energy (Kontopoulos et al. 2016). Indeed, according to International Energy Agency (IEA, 2011), heat represented 47% of the final energy consumption in 2009 with the building sector accounting for more than 40% of the final energy consumption in the EU. As a result, building energy efficiency attracted increasing research efforts in recent years. At the same time, benefits of green buildings are obvious (Nilashi et al. 2005): air and water quality improvement, waste streams reduction, natural resources conservation and restoration, minimizing global warming, etc. Therefore, as noted by Shelbourne et al. (2006), the construction industry is having a tendency to include sustainability aspects into its daily practices.

Nilashi et al. (2005) described a knowledge-based expert system for assessing the performance level of green buildings from the environmental, social and economical perspectives. They presented a tool, which operated on the basis of fuzzy logic, and analyzes the effect of different factors in sustainable building development.

Hercheui (2011) analysed behavior change under influence of knowledge management tools. For the illustration they use Microsoft Holm, free-of-charge Internet tool, which helps householders to better manage energy consumption. Data obtained from the best management practices, were compared with household data and based on that, householders have received instructions on how to improve energy consumption.

Venters et al. (2005) used soft system methodology as a way to increase in construction industry practice. Tan et al. (2012) presented web-based knowledge management system to support higher education institutions in the course of sustainable construction. Shelbourne et al. (2006) described tools, methods and architectures for creation, sustaining and disseminating knowledge for sustainable construction, they have presented C-Sand portal, an integration tool.
Kontopoulos et al. (2016) presented an ontology-based decision support tool for optimising domestic solar hot water system selection. Fan et al. (2015) described data mining methodology for knowledge discovery in big building automation system data, and suggested method for the efficient post-processing of knowledge discovered. Method, proposed in that paper, helps not only reduce energy consumption of the building, but also decrease the required computational costs. However, Pietrosemoli and Monroy (2013) conclude that limitations in the mechanisms to promote knowledge processes in green construction industry still exist.

Disaster or Emergency Management

Disasters have a complex and dynamic environment; therefore, KM systems must operate along with a high degree of uncertainties. Dorasamy et al. (2013) presented a literature survey dedicated to KM systems in support of disasters management, in particular to knowledge-based emergency management information systems. According to the paper, simulation tools, DDS and sensors network are the most popular technologies for disaster management.

Stojanova at al. (2010) presented improved models that predict the risk of fire outbreaks in Slovenia by using state-of-the-art data mining techniques. Another research on managing fire was made by Liu et al. (2010), who described Geographical Information Systems and information diffusion-based methodology for spatio-temporal risk analysis of grassland fire disaster to livestock production in the grassland area of the northern China.

Environmental Monitoring and Natural Resource Management

Environmental monitoring describes the processes and activities that need to take place to characterize and monitor the quality of the environment. Cash et al. (2003) described a framework for understanding the effectiveness of systems that link knowledge to action for sustainability. They provided several case studies, presented applications of KM for environmental monitoring, in particular, for managing ocean fisheries, reduction of transbondary air pollution, El Nino forecasts, and enhancing agricultural productivity. Agricultural productivity is a main theme of the paper, written by Lwoga (2011). The paper described the application of KM for improved farming activities in Tanzania. Linger et al. (2013) suggested task-based knowledge management (TbKM) approach for application to the case of natural resource management in Indonesia in the context of economic development and response to climate change.

Sustainable Manufacturing and Product Development

The US Department of Commerce's Sustainable Manufacturing Initiative defines sustainable manufacturing as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound"
(http://trade.gov/competitiveness/sustainablemanufacturing/).

The optimization of resources and energy consumption of production systems is one of the fields in which industries should make relevant improvements in order to successfully integrate sustainability aspects in the Factory of the Future (Belkadi et al. 2015). Sustainable manufacturing today is a business imperative. Indeed, according to Vikhorev et al. (2013), in 2008, the global industrial sector consumed around 98 EJ of energy and this figure was expected to increase by 44% between 2006 and 2030. 28% of European energy use was consumed by the industrial sector. Manufacturing industry is also responsible for 38% of global CO2 emissions (IEA, 2007). These figures indicate the necessity of using KM processes and systems in order to provide energy optimization and reduce CO2 emissions.

Vikhorev et al. (2013) presented the framework for energy monitoring and management in the factory. Belkadi et al. (2015) described knowledge based and product lifecycle management facilities for sustainability perspective in manufacturing. The paper presents guideline, that helps to apply the knowledge model in a specific manufacturing domain. Trotta (2010) presents different tools in order to optimize product lifecycle management. Gamarra et al. (2016) describes knowledge discovery method that allows minimizing environmental impact of manufacturing processes and make it more sustainable.

Sustainable Transportation and Supply Chain Management

Sustainable transportation can be defined as one that is able to meet transportation needs without compromising the ability of future generations to meet their transportation needs (Richardson, 2005). It is affordable, operates efficiently, limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, reuses and recycles its components.

Awasthi (2011) described multi-criteria decision-making system that helps to evaluate sustainable transportation. The system identified the criteria for sustainability, then experts provide "linguistic ratings to the potential alternative against the selection criteria", selected the best possibility and determined "an influence of criteria weight on the decision making process". Srivastava (2011) presented method based on Virtual Sensors technique that helps to detect overconsumption of fuel in aircraft, and, therefore, reduce the environmental impact of the aviation. Liu et al. (2016) provided method of intelligent bus routing that helps to improve the efficiency of public transportation services, based on people's actual demand for public transportation.

DISCUSSION AND CONCLUSIONS

The paper is focused on current research status of using knowledge management systems and processes in green ICT and ICT for greening.

Figure 3 reflects different technological tools that were applied in order to support KM processes. They included decision support systems (DSS), knowledge based systems, data mining technique, web portals and Internet tools, simulation tools, sensors, GIS, service-based applications, etc. As stated by the Figure 3, the most frequently used technologies, enlisted in the papers, are DSS, data mining, web portals and knowledge-based systems.
DSS are mentioned in eight papers, for example, by Awasthi et al. (2011), Majchrzak et al. (2011), Pinto et al. (2015), Smirnov et al. (2011), Stojanova et al. (2012), Vikhorev et al. (2013). DSS are a

commonly used technology for knowledge application systems and processes that "support the process through which some individuals utilize knowledge possessed by other individuals without actually acquiring that knowledge" (Becerra-Fernandez, 2010). As it follows from the table 1, DSS are widely employed by disaster management, where decision-making process, decision quality and timeliness is highly important.

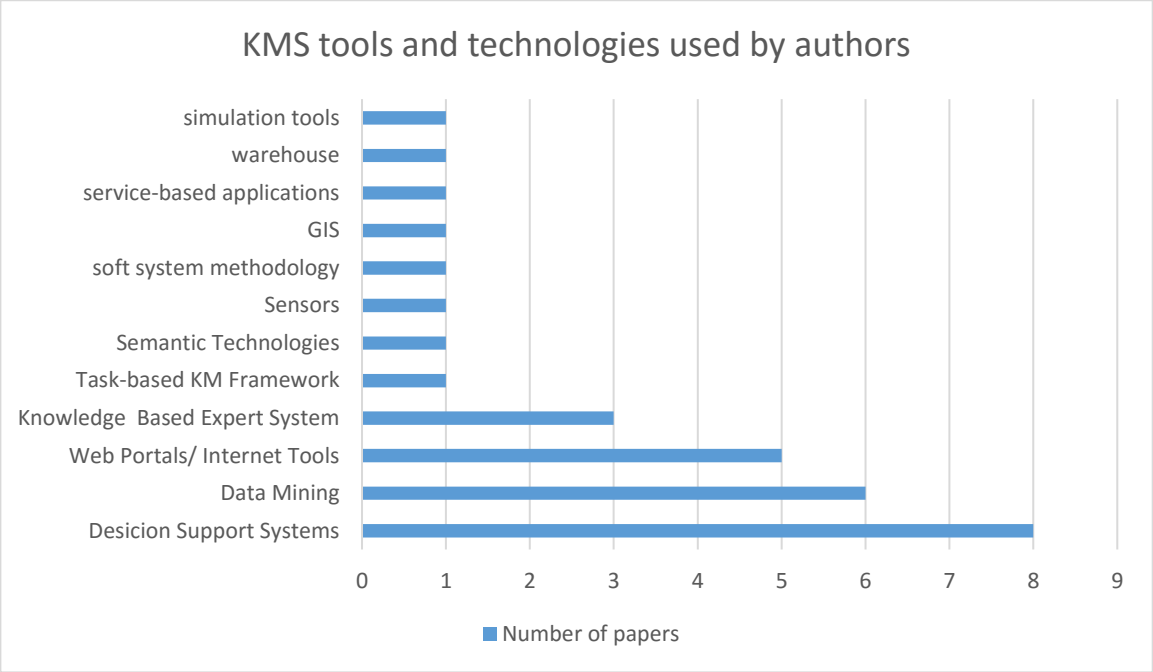

Figure 3. KMS tools and technologies used by authors

DSS are followed by data mining (six mentioning) and web portals/internet tools (five mentioning). Data mining enables knowledge creation systems and it is utilized for the knowledge discovery process. Examples of such applications are listed by Fan et al. (2015), Morik et al. (2012), Shaheen et al. (2011), etc. They have been applied for such areas as green construction or energy sector for temporal knowledge discovery in big building automation system data. Web portals is one of the most popular tools for knowledge sharing, aimed for exchange knowledge and information as platform of the AES-CE (Sharing Experiences for Site Specific Agriculture) described by Howland at al. (2015).

Therefore, analyses of the literature have proved the existence of many different strategies for application KM to ICT for greening fields, such as green building and constructions, disaster management, natural resource management and environmental monitoring, sustainable manufacturing, sustainable transport, etc. However, review results also show that an urgent need still exists in investigation of application KM systems and processes to the field of green ICT. Apart from green datacenters and green software development, there are many other fields such as green networking, green hardware, pervasive computing, etc. Therefore, much more work could be done in that field.

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IMPLEMENTING A CIRCULAR ECONOMY AT CITY SCALE – A CHALLENGE FOR DATA AND DECISION MAKING, NOT TECHNOLOGY

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ABSTRACT

The circular economy currently receives considerable attention as policy outcome or design intent, with the main focus on how to close resource flow loops, tackled as a problem for technologies to solve. This builds on academic literature of resource efficiency and in particular the concept of an 'urban metabolism'. Closing resource loops is rarely presented alongside spatial analysis but as cities are significant sites of concentrated resource use, spatial considerations need to be introduced to the discussion of the circular economy.

This paper presents a process for identifying circular economy actions, which can be deployed at the city scale. Without preferring particular technology solutions, we propose a systematic process identifying options for re-use and recycling before investing in material transformation and energy recovery. At each stage of the process there are different requirements for data, and for governance structures.

The process was developed and tested using the city of Leeds as a case study. Datasets for waste, water, energy (electricity and heat) and other resources (e.g. land) were identified and analysed. We found that the barriers to increasing circularity are twofold. First, consistent, coherent and congruent datasets describing resource flows are not available. Second, there is no (or not enough) citywide capacity to ensure circular economy actions are systematically implemented to realise the social, environmental and economic potential of the circular economy at city scale.

The paper does not advocate gathering more data or creating complex models. Instead we suggest three foundation datasets and two governance factors which need to be in place to create a platform for the city-scale circular economy to be developed. Once this platform is established, five further datasets and two more governance factors help shape plans for effective implementation of the circular economy opportunities which the city-scale process helped to identify.

INTRODUCTION AND BACKGROUND

Driven by finite resource availability, increasing resource costs and the challenge of disposing of increasing volumes of waste material with attendant environmental impacts, the concept of the "circular economy" has emerged as an alternative to the linear ('take-make-dispose') model of resource use. The design processes that are needed to move to a circular economy are characterised as "cradle to cradle" rather than "cradle to grave" (McDonough & Braungart, 2002). Moving beyond product or process design, the wider idea of the "circular economy" as championed in the UK by the Ellen MacArthur Foundation (2013) seeks ways of moving to an economic system where resources are used and then returned to productive use, never thrown away or disposed of to landfill.

The European Union (EU) has become an increasingly interested actor in driving the development of a circular economy by developing policy and providing funding to pursue new methods of waste management. The EU's policy goal in their 2015 'roadmap' is:

> *"By maintaining the value of the materials and energy used in products in the value chain for the optimal duration and by minimising waste and resource use, the circular economy can promote competitiveness, innovation, a high level of protection for humans and the environment, and bring major economic benefits, thus contributing to growth and job creation. It can also provide consumers with more durable and innovative products that provide monetary savings and an increased quality of life."* (EC, 2015)

Growing global urbanisation is also driving interest in the circular economy. A total of 54% of the world's population now live in an urban setting and there are more than 28 mega-cities with a population of greater than ten million (UNDESA, 2014). Increasing urbanism means that waste management will become an increasingly complex challenge for city infrastructure. Cities are major sites of consumption, e.g. mega-cities such as Beijing and Mexico City produce 4,134,000 and 4, 562,000 tonnes per year (Waste Atlas, 2016). Other cities have more intense resource consumption rates e.g. San Francisco and Cairo generate 609 and 625 kg of waste per capita per year respectively (Waste Atlas, 2016). This raises the question at the heart of this research: "How do we develop more circular economies at city scale?"

The idea of an "urban metabolism" is well established and provides a useful starting point for thinking about the circular economy at city scale. Developing from Herbert Girardet's (1999) seminal work on sustainable cites from a planning and architecture perspective, there is increasing discussion of combining urban metabolism and circular economy principles to create "circular city metabolisms" (Zaman & Lehmann, 2013). Thinking about "urban metabolism" suggests the city as an organism that encompasses "the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy *et al*, 2007). Research exploring the urban metabolism of different cities often has the goal of reducing waste streams and achieving a zero waste city. As well as examining resource flows at the city scale, there is a need to explore resource flows at a variety of scales, together with the circular business models which allow resource loops to be closed. In a recent review of urban metabolism research, Zhang et al. (2015) identify that multiscalar approaches are required, and this paper presents ideas responding to that call for further research. In addition, the idea of the "urban metabolism" alone is not enough to deliver a circular economy at city scale. A higher metabolic rate may mean more resource use, more throughput of resources, which could lead to a growth in economic activity but not necessarily

ensuring sustainable development as measured by the well-being of citizens and supporting lifestyles and resource use within environmental limits.

This paper offers city planners and urban policy makers (and their advisers) ideas to help develop a policy framework that encourages and enables spatially-constrained circular economy activity. In developing and testing a novel framework that combines circular resource economy thinking with established approaches to waste management, we identified a wide range of stakeholders and decision making processes which could play a role in city-scale circular economy action. The data that these actors need goes beyond the description of resource flows alone, even though that descriptive data is complex enough at city scale! For a city to develop a more circular economy, a comprehensive policy framework that touches upon spatial planning, economic development, skills, environmental quality, energy and health is needed, indicating that data describing waste management is insufficient. After exploring the empirical data related to resource flows gathered in one city, we propose a suite of datasets that are part of making the case for a coherent policy framework that would be transferable to many other cities. The purpose of this approach would be to ensure that technological and social entrepreneurship can play complementary roles in a whole-city circular economy with attendant social, environmental and economic benefits.

What is the current focus of circular economy research?

A review of articles with keywords "urban" or "city" and "circular economy" identified 178 peer reviewed publications, all published since 2002. The abstracts of these articles reveal them as mainly resource-specific or location-specific where resource use is already intense for example, a study of the iron and steel industry of Wu'an city in China (Ma *et al*, 2014). Commercial research focuses, understandably, on where there is value to be retained in materials and again, this is likely to be material-specific (Veolia, 2015).

There is no shortage of innovative solutions that can close resource loops at a variety of spatial scales. A rapid review of on-line sources reporting circular economy activity and excluding energy from waste projects identified 79 distinct current initiatives. However, only 14% of these were city-scale in their ambition or achieved scale. If technology solutions are not constraining the development of city-scale circular economies, what is?

This paper presents a model which attempts to incorporate some of the non-technology factors necessary to implement a circular economy. In particular, alongside evaluating the datasets that help a city develop circular economy activity, we explore the decision-making processes or 'governance' factors that support a city in such activity. By governance we mean the "patterns of rule" by which the state and public sector interact with other organisations for decision making and resource allocation which decide policy priorities and identify actions to respond to those priorities (Bevir, 2009).

Developing a framework for the city-scale circular economy

From a city manager's perspective, the focus of activity for changing resource use will usually be on managing waste arisings rather than reducing resource inputs to the city or reducing levels of resource consumption. City authorities are responsible for managing domestic waste and city infrastructure includes waste management facilities that handle both domestic and commercial

waste. Waste management and planning is underpinned by the "waste hierarchy", a series of steps which aim to reduce to zero waste that is disposed of to landfill (DEFRA, 2011). Represented as an inverted triangle, the waste hierarchy prioritises re-use of materials, above recycling, above recovery (e.g. energy from waste) before the final option of disposal to landfill.

We have therefore developed a framework which combines the elements familiar to city authorities (the waste management hierarchy) with the ideas of the circular economy. This framework is represented in Figure 1 with the three levels of the hierarchy described in Box 1. Resource flows are presented by the downward spiral set above the spatial constraints of the city. The layers of the spiral reflect the waste hierarchy, with resource flows being evaluated for their potential for re-use, before then being evaluated for their potential for recycling and retaining their original function, then recycling and changing their originally function, before being considered as a material ready for transformation, typically into energy that can be used in the city.

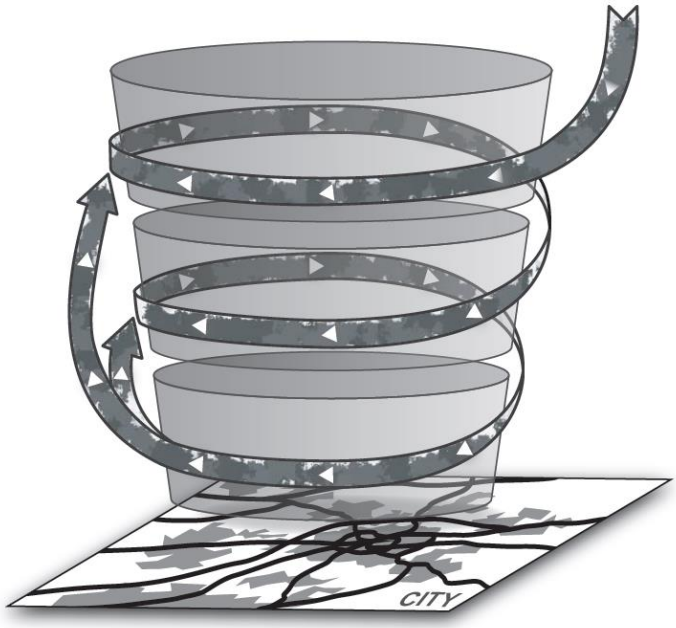

Figure 1: Combining the waste hierarchy and the circular economy at a city-scale.

Can this material be reused? (If the answer is Yes, reuse activities can be discussed and developed. If answer is No move down to the next level / question)

Can this material be recycled? (If the answer is Yes, assess whether recycling to the same material, or recycling to a different material is feasible. If answer is No move to the next level / question)

Can this material be transformed? (If the answer is Yes, identify whether the city infrastructure allows for the material to be transformed and used).

By systematically exploring opportunities for re-use and recycling before evaluating resource transformation potential, a diverse set of city-based organisations can be involved. For example, in the early stages of this framework where material commercial values may be lower or diffuse, re-use and local recycling of waste may be best facilitated by community groups, charities and social enterprises so that social benefits are realised alongside environmental benefits. Lower down the process, where options may be more technology-intensive, commercial interests and private sector organisations with better access to financial capital may be better placed to realise the opportunities and deliver economic benefits alongside environmental benefits.

Using the framework to explore data and governance issues

Our research then used this framework to evaluate the data available describing resource flows in one city (Leeds). Leeds is a medium sized city in the industrial/post-industrial north of England i.e. a developed country context. This context needs to be acknowledged as cities in different contexts will have different patterns of resources use, governance, and therefore circular economy opportunity. The limitations of using Leeds as the exploratory case, and what this means for the transferability of the proposed framework are revisited in the conclusions of this paper. Data describing water, waste and energy resources were collated from a variety of public and private sector sources. Table 1 lists the sources identified and categories of data they could provide.

		Description of source	**Waste**	**Water**	**Energy**	**Other**
1	Arup	International engineering and design consultancy firm	X			
2	Associated Waste Management	Private sector	X			
3	Biffa	Private sector	X			
4	Department for Energy & Climate Change	National government			X	
5	Department for Environment & Rural Affairs	National government	X			
6	Environment Agency	Environmental regulator	X	X		
7	Green Gain	Regional consultancy	X			
8	Leeds city council – energy team	Local government			X	
9	Leeds Data Mill	Open source platform, public sector funded			X	X
10	Leeds Observatory	Public sector data repository				X
11	OFGEM (Office of Gas and Electricity Markets)	Economic regulator			X	
12	Northern Gas Networks	Distribution network operator			X	
13	Northern Powergrid	Distribution network operator			X	
14	Veolia	Private sector	X		X	
15	Waste Data Interrogator	On-line platform – supported by environmental regulator	X			
16	WRM	Regional consultancy	X			
17	Yorkshire Water	Private sector utility	x	X		

Table 1: Sources of data relevant to developing a city-scale circular economy in Leeds

Datasets were identified through a series of expert interviews with individuals in many of the organisations listed in Table 1. Interviewees were recruited by direct approach following a mapping of relevant organisations relevant to the circular economy in the city. Interviewees were approached with a project summary and information sheet to support full, prior and informed consent in line with University ethical standards, and interviewees participated in their professional roles, often as representatives of their organisations. While the majority of datasets gathered, particularly those relating to energy, some aspects of water, and waste were all in the public domain, other datasets had aspects of commercial confidentiality associated with them. The project team signed non-disclosure agreements where necessary to allow discussion of the datasets to be part of the research process, even if the dataset itself could not be released. In practice, what the research required was the metadata for each dataset: what resources did the dataset describe? What was its frequency and issue date? What was its spatial coverage, confidence level, exclusions, ownership and so on? By recording and analysing metadata rather than the individual datasets, issues of confidentiality were managed effectively. All research participants were also offered the opportunity to take part in the process of further policy and action development in the city, so that there was the opportunity to benefit from participation in the research.

This table illustrates the diverse data sources relevant to developing a circular economy in a specific city. Each city will have a different set of sources depending on regional and national regulation and governance arrangements. For example, in many administrations, water supply and treatment is a public utility, whereas in the UK it is a private sector function.

These datasets were evaluated with regards to whether they individually or collectively provided a full (empirical) picture of material flows in the city. We attempted to match data sets in order to trace material flows. We found significant challenges in terms of data completeness, congruence, and consistency.

- Completeness – Volumes of 'uncoded' or 'unrecorded' waste is considerable throughout the UK. Reasons given by data owners for this centre on commercial confidentiality.

- Consistency – Different datasets declare different statistics whilst describing the same cities. Differences in collection methods as well as definitions of key terms (such as municipal waste) may be the reason behind this inconsistency.

- Congruence – Spatial boundaries do not necessarily match when it comes to the city-scale resource flows. For example, neither the catchment of a city's water treatment works or the areas served by electricity substations is likely to be identical to the city's municipal boundary.

Several of the private sector partners we spoke to were actively working on initiatives which would contribute to a more circular economy in the city. In order to do this, they were working with bespoke datasets, often new primary data that they had collected for the purpose of their project.

Discussion: data and governance factors to be addressed for this framework to support the circular economy at city scale

From mapping and collecting metadata for the datasets available describing resource flows in Leeds, we identified two distinct groups of datasets which are required to use the city-scale circular economy framework.

The first group are the "foundation" datasets; the datasets which describe the resource flows in the city:

- Volume (quantity) of resource flows
- Material type of resource flows
- Quality/Consistency of resource flows, by material

Understanding these three datasets helps start the process of city-scale circular economy design by scoping what re-use, recycling and transformation activities may be feasible. Feasibility here includes consideration of whether there is sufficient quantity (volume) of a given material (content and quality) to allow for a given technology of re-use, recycling or transformation, assessed in that order. For example, are there sufficient coffee grounds to support a commercial composting scheme to generate food grade compost (Fletcher, 2015)? Or commercial production of gourmet mushrooms (Champignon de Bruxelles, 2016)? The financial viability of such options is not considered at this scoping stage, in the use of the framework as proposed.

The volume dataset could be developed from modelling rather than empirical measurement. In cases where resource flow volume or quality varies seasonally (such as in raw water availability or pollutant concentrations from drainage and water run-off) these variations are likely to be well understood. Thus a modelled flow, rather than frequent empirical measurements, can still deliver the same functionality for the purposes of scoping potential actions within a city-scale circular economy. However, we are not advocating (investment in) extensive modelling. The data need only be "fit for purpose" for scoping, and in many cases simple manipulation of existing flow monitoring will be sufficient to generate the foundation datasets.

However, even when data describing resource flows is available and technologies are feasible, there are still barriers to implementing the circular economy in the city. These barriers can be characterised as "governance" issues and factors.

Again, we identify "foundation" factors which need to be in place before the systematic process of identifying opportunities can be undertaken. The two foundation governance factors are (a) establishing a coherent policy framework for the city to develop a circular economy, linked to all relevant policy spheres and (b) putting structures in place for stakeholder engagement across public, private and voluntary sectors.

Establishing a coherent policy framework means ensuring that a range of policy areas all see a city-scale circular economy as a way to achieving their individual policy goals. Committing to support a circular economy is relatively easy for waste managers as a circular economy will reduce the amount of waste disposed of to landfill, a key waste policy goal. However, the linkages are less direct for other policy areas such as skills (where deliberate actions to support re-use / remanufacturing skills need to be made), energy (where energy from waste ambitions may need to be modified to ensure

that reuse and recycling opportunities are realised) or land use planning (where zoning of land for waste management can often be contentious and prevent small scale re-use or recycling operations). In Leeds we identified eight distinct policy areas that would need to be engaged to help create the policy environment to encourage the growth of a city-scale circular economy, listed in Table 2.

POLICY AREA	LINKS TO CIRCULAR ECONOMY IN THE CITY
LAND USE / PLANNING	Zoning re-use and recycling enterprises (as well as collection points)
WASTE / PLANNING	Waste and planning policy can go beyond avoiding landfill to recovering resources, and the infrastructure required to do this must be identified.
ECONOMIC DEVELOPMENT	Identifying the sectors which offer opportunities for enterprise and employment
ENVIRONMENTAL QUALITY	Incentivising the recovery of 'pollutants' for recycling (and re-categorising them as resources)
TRANSPORT PLANNING	Planning for infrastructure using waste-derived fuel
PUBLIC HEALTH	Reducing pollutants can provide an opportunity if those pollutants are recovered
EDUCATION & SKILLS	Skills to describe, analyse, design and implement resource recovery are needed in a range of roles.
ENERGY AND CARBON	Carbon reduction targets help to drive Type C circular economy actions

Table 2: Leeds City Council Policy areas relevant to the circular economy.

The need for widespread stakeholder engagement is driven by using a framework for the city-scale circular economy which prioritises re-use and recycling before material transformation processes. While a global review of social media coverage of circular economy initiatives showed that different forms of enterprise work at all "levels" of the framework, there is a general tendency for social enterprises and community initiatives to focus on highly localised initiatives of re-use, or recycling, while larger private sector firms are better equipped to operate at city-scale where the costs of technology or infrastructure may be higher, and the potential commercial rewards for material recovery are higher. A platform for stakeholder engagement which recognises the importance of these different and complementary capacities serves two purposes. First it ensures that the most appropriate actors are engaged at the appropriate scale and "level" of the framework. Second, it creates the potential for partners with different capacities, constraints and motivations to work together in order to overcome constraints.

In the UK, the waste regulation, enforced by the Environment Agency includes a requirement for any organisation receiving or processing a waste material to hold a waste management licence. Any material disposed of is a waste. Thus a small organisation or social enterprise seeking to implement a re-use or recycling activity in a local area – such as composting – must also have the capacity to deal with regulatory requirements, become a licensed organisation and so on. Using this systematic framework, underpinned by stakeholder engagement, might provide a route for social enterprises to link with other organisations, public or private sector, who have core competencies in meeting

regulatory requirements and waste handling, as well as engaging the regulator in a discussion about appropriate designation of materials.

The foundation data sets and governance actions place the city at the top of the spiral in figure 1, moving towards a city-scale circular economy is feasible, so the next challenge is to move down the spiral following the steps in Box 1.

Once these 'foundation' aspects of city resource flows and capacity are understood, a further five types of dataset can be helpful in using the framework i.e. to select options for re-use, recycling or transformation, and to indicate the types of technologies or infrastructure needed in the city to implement those options. These five "implementation" datasets are:

- Calorific value: the amount of energy which it could release, usually when combusted. Calorific value determines viability of some transformation activities at the bottom of the spiral e.g. energy from waste.
- Financial value: on the cost of the component materials (less cost of recovery) or the potential value of the material after recovery/re-use. Some materials have market value (e.g. metals). Other materials will have a value based on the opportunity cost of not disposing of them. This is where the financial viability of the options identified from the 'foundation' datasets can be evaluated.
- Sources: Spatial mapping of locations where resource is produced
- Collection points: Spatial mapping of infrastructure or sites which serve to collect resources.
- Regulatory constraints: Clear assessment of material flows subject to regulatory constraints in their re-use, recovery or treatment because they are designated "pollutants", "hazards", "controlled" or "waste". Designation may be context specific.

In addition there are two further governance factors which will affect how well the city is able to follow up on the opportunities identified and described through these datasets. These two factors are whether there are:

- institutions in the city to collect, process and distribute resources,
- sufficient skills and knowledge in the city to implement the actions that technology enables.

In our Leeds case study, institutions to collect and process resources safely and legally were not well documented or understood outside of conventional waste management and disposal processes covered by "Duty of Care" regulations (Environment Act, 1990). Equally, while there may be skills that could support a city-scale circular economy, the lack of policy focus in this area meant that it was impossible to assess the availability and level of these skills.

CONCLUSIONS

When charged with exploring how a city-scale circular economy might be developed, without pre-judging the necessity of a specific technology, we found there was a need to develop a framework for assessing the many options for closing resource loops. Combining aspects of the established waste hierarchy with circular economy concepts and placing these within the spatial constraints of a city provides a novel framework which allows city-specific opportunities to be identified systematically.

In reviewing current activity and research on developing a circular economy, we found limited attention to how spatial constraints, or the city as a dynamic context, might affect circular economic activity. There is much more focus on technological innovation to close resource loops, and how implementing technologies at city scale can drive further innovations. The framework proposed in this paper is intended to be complementary to these technology-driven approaches. We suggest that by starting with an understanding of resource flows and existing assets (including social and economic assets, as well as environmental assets) in a city, a plan can be developed which uses more of the distinctive aspects of the city, includes more actors in the development of the circular economy, and therefore delivers benefits across a range of policy domains.

Following the spiral presented in this framework from top to bottom, retaining resources (and value) within the spatial limits of the city supports a variety of city-specific responses. A diverse economy, whether circular or not, with activity across many sectors with many forms of enterprise is more resilient to changes (Rockefeller Foundation, 2015), which could be an important co-benefit of developing a city-scale circular economy in this way.

Clearly this framework, and particularly the data and governance factors that we have identified, have emerged from in depth analysis of only one city's data and institutions. Further research examining how the framework might be applied in other city contexts would be very helpful in improving the robustness of the proposed framework. In particular, there is a need to explore the potential of the framework in cities where patterns of governance are different i.e. where utilities are publicly owned / managed or where a city authority's economic and environmental powers are more devolved than in the UK. In addition, it would be useful to compare the Leeds analysis with the use of the framework in a city in a developing or middle income economy, where the informal economy related to waste management may already be substantial, and where spatial planning may not be rigorously undertaken or enforced. As well as identifying that the governance and regulation of utilities varies between cities, and that developing country cities are likely to have very different issues and potentially more capacity to keep circular economy activity nearer the top of the framework, we also recognise that global cities have distinctive patterns of governance, developed from a heady mix of culture, economic power, urban design and political ecology. The framework is not offered as a recipe, rather a guide to approaching circular economy activity at the city scale.

Despite these limitations, this paper demonstrates that it is possible to think about, and develop, a city-scale circular economy without committing to particular technology options or infrastructure as the starting point. Pursuing a city-scale circular economy through systematic consideration of the waste hierarchy, and including the range of stakeholders who can contribute to that circular economy, could deliver multiple benefits in terms of resource efficiency, waste reduction, employment and resilience.

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Education and Sustainability

THE USE OF RENEWABLE ENERGY SYSTEMS TO IMPROVE EDUCATION INFRASTRUCTURE IN SOUTH AFRICAN RURAL SCHOOLS

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ABSTRACT

The public school education system in South Africa was shaped by Apartheid and is characterised by underdevelopment with large disparities in the distribution and quality of education infrastructure. Public rural schools in the Eastern Cape continue to suffer from acute infrastructure shortcomings resulting in adverse consequences for learning which is deeply connected with the problem of poverty in rural communities. Furthermore, the school is often the centre and only government building in a rural community, serving as a community hall, adult education centre and facility for administering social grants. The lack of electrical infrastructure in rural schools, due in part to power utility Eskom's inability to service these communities, affects the quality of education delivered as well as the potential to maximise the use of the premises. The aim of the study was to better understand the potential for the use of renewable energy as well as identify the constraints to its more widespread implementation in rural school building programmes. A quantitative questionnaire was used to elicit responses from various built environment professionals who have worked in the Eastern Cape schools building programme. The outcome of the research highlights that un-electrified schools are mainly in communities lacking electrical grid connectivity, that there is potential for solar power as an immediate solution on most projects but that alternative energy systems are not considered in the design scope of projects. Budgetary constraints and security concerns are the main barriers to the adoption of the technology despite legislation requiring electrical installation in all new buildings. Furthermore, research suggests that by providing power, internet connectivity can be established which will provide immense potential for expanded learning to occur whilst use of a public-private model would enhance the potential for the installation to be self-funded, eliminating the cost related funding issue.

INTRODUCTION

Energy, particularly electricity is acknowledged as an enabler of socioeconomic wellbeing, as aptly espoused by the South African government (Njikelana, 2014). South African rural communities, like the rest of the continent are faced with chronic infrastructure challenges. The lack of basic electrical infrastructure in particular has adverse consequences on development efforts in such areas. South Africa has vast energy potential and all the available alternative energy solutions to bring electricity to remote rural regions are available but are not an integral part of the energy supply debate. With over 24,000 public schools spread out across the land, built environment professionals are tasked with the design and management of schools infrastructure projects on behalf of the government but these self-same 'professionals' have limited input into the scope of works particularly with respect to the energy mix. These consultants are, however, at the coalface of the struggle faced by schools and their opinions on the use of alternative forms of energy to address this problem were therefore a target of this research.

Further, the geographical isolation and therefore remote proximity to cultural and educational amenities has a limiting effect on learner's development. In addition, many rural areas remain without grid electrical infrastructure and when schools are built in such areas, alternative energy sources are not considered. The quality of rural education and its potential for development is deeply connected with the problem of poverty in rural communities. The scarcity of resources in these remote areas has the consequence of seriously limiting the developmental possibilities that might be achieved through education. This means that the great majority of children in rural poor communities are receiving less than is their right in a democratic South Africa. The lack of electrical infrastructure in rural schools continues to be a problem that affects the quality of education delivered, a situation unlikely to be resolved by the state power utility Eskom due to its dire financial situation. There are numerous initiatives by the private sector to help government to achieve electronic connectivity to rural schools and communities. However, the bulk of the effort needs to come from the government and much more needs to be done. This problem coupled with advancement in renewable energy technology created the need for this study.

RURAL COMMUNITIES AND THE CHALLENGES IN EDUCATION

The lack of basic services affects every aspect of community life: daily living, schools, clinics and recreational facilities (Nelson Mandela Foundation, 2005). According to Daphne Gumbi (2009), rural communities lack piped water, electricity, roads, health and educational facilities; requirements that are necessary for human development. When a community goes without water or electricity, the schools also suffer. Schools are inseparable from the communities they serve, and without a holistic approach to the general conditions of poverty; neither the school nor the community can address the challenges (Nelson Mandela Foundation, 2005).

There is no question that government policies prior to 1994 led to significant backlogs in school infrastructure in particular regions and, specifically, for black learners. However, 20 years into the new democracy, it would be reasonable to expect that the worst examples of inequality would have been addressed; that children would not be learning under trees or in conditions that are dangerous or completely dysfunctional (Centre for Child Law, 2014).

Equal Education (2015) further emphasized that those schools in the Eastern Cape and KwaZulu-Natal are the worst affected. Efforts to improve public schools infrastructure include the establishment of a dedicated unit to speed up schools infrastructure delivery called the Accelerated Schools Infrastructure Delivery Initiative (ASIDI) and the legislation of minimum requirements for 'ideal' schools. These efforts run parallel to the conventional school building program. According to the Department of Basic Education (2014), the objective of ASIDI is to eradicate the Basic Safety Norms backlog in schools. That means it focuses on replacing schools with unsafe or inappropriate structures, schools without water, sanitation and electricity in order to contribute towards higher levels of optimum learning and teaching. Inappropriate structures are buildings that have been constructed from inappropriate materials such as asbestos, corrugated metal, mud and wood.

The South African power utility, Eskom, generates 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa. It owns and operates the national electricity grid. While Eskom does not have exclusive generation rights, it has a practical monopoly on bulk electricity in South Africa. The state utility is going to be under intense pressure for years to come to build enough generation capacity to meet the country's needs. The World Bank is a crucial source of funding. Initially reluctant, Eskom has become enthusiastic about renewables in part, to keep the World Bank happy. The bank itself is under intense criticism for lending $3.7 billion to Eskom to fund the gigantic Medupi power plant that will eventually consume 15 million tons of coal a year. To get access to World Bank funding, Eskom has had to demonstrate that it is willing to curb emissions. And that means renewables (du Venage, 2013).

In 2015, Eskom announced that it faced a R225-billion revenue shortfall as a result of it being granted increases of 8% between 2013 and 2018 as compared with the 16% it had sought. With a R225-million revenue shortfall over five years, Eskom will remain dependent on the government (and tax payer) for the foreseeable future and therefore will be limited in terms of using South Africa's abundant solar resources especially in the Northern Cape and ideal average wind conditions along its over 2 500 km of coastline, not to mention excellent clear sky conditions for rooftop solar photovoltaic installations.

Toni (2005) agrees that many of the challenges facing education can be traced to the country's past. However, not enough has been done in the intervening 20 years to address the inadequacies created as a result of apartheid and the homelands policy that created Bantustans. According to Equal Education (2015), the 2011 National Education Infrastructure Management Systems (NEIMS) Report identifies 24 793 schools in the country of which 3544 do not have electricity and a further 804 schools have an unreliable electricity source. The latest NEIMS report published in October 2014 reports that there are now 23 740 ordinary schools in SA, 1131 of these do not have electricity at all, and a further 2 773 schools have an unreliable electrical supply. In the EC, a province of two of the Bantustans, there are 5 468 ordinary schools, where 377 do not have electricity and 1 450 have an unreliable electrical supply. This means that 33% of the schools without electricity in SA are in the EC and 52% of the schools without a reliable electricity supply are in the EC. 1 827 (377 + 1450) out of 5 468 schools in the Eastern Cape do not have a reliable electrical source. According to the Eastern Cape Department of Education (Education Management Information Systems, 2015), 3104 out of the 5767 schools in the province (54%) are in rural areas. Equal Education (2015) citing the NEIMS Report (2011), that of the 24 793 ordinary schools in South Africa at the time, 22 938 schools do not have stocked libraries, while 19 541 do not have a library at all. 21 021 schools do not have laboratory facilities and only 1 231 have stocked laboratories. 19 037 schools do not have a computer centre and 3 267 have a computer room but it is not equipped with computers.

The South African Schools Act: 'Regulations relating to minimum uniform norms and standards for public school Infrastructure' (2013) provides that all schools must have some form of power supply that complies with all relevant laws. In addition, the regulations state that 'the forms of power supply may include grid electrical reticulation, generators, solar powered energy or wind powered energy sources'. The power supply must be sufficient to serve the power requirements of the school and must be based on the most appropriate power source available. Renewable energy systems are a viable solution for energy provision in rural schools. In the Far East and on the African continent, various companies and governments use innovative, alternative solutions to bring electricity to schools in remote areas. Samsung Electronics Africa, through their CSI initiative with NGO Habitat for Humanity, is piloting solar powered internet schools in rural areas across the continent. The schools are housed in 12m shipping containers with foldaway solar panels that can provide electricity for 24 hours and have storage for up to a week when there is no sunshine. Electrification would enable internet connectivity and improve learning delivery. Panasonic have the Power Supply Container, a system using a combination of high efficiency solar modules and batteries to supply electricity at remote island locations and specifically to schools. The system can be configured to supply surplus electricity to the surrounding community when the batteries are full.

Various non-governmental organisations and companies have dedicated initiatives to achieve electronic connectivity in rural schools and communities. ClickMaths, an NGO based in Cape Town makes mathematics content available to underprivileged learners in English and Xhosa. Vodacom has a website called e-school which provides lessons for grades 8 -12 for most of the subjects in the high school curriculum. In addition, they have 40 teacher centres countrywide to offer teacher development training and specifically ICT skills training in all subjects. Discovery Education, through their website, offers virtual tours of mines, navy vessels and other scientific attractions. The site also has online science competitions for schools where learners can compete with schools across the globe, has new teacher survival kits and many lessons from driving safety to economics essentials.

RESEARCH REVIEW AND METHODOLOGY

Information regarding schools infrastructure can be found on government websites, in publications from non-governmental organizations and from other education stakeholders including Equal Education. However, although this information is comprehensive in terms of statistical data, it has little project specific information relating to the delivery of projects and therefore it was necessary to collect information from a group that experience and attempt to solve the problems faced by public schools, Built Environment professionals contracted to the Department of Public Works for the design and management of school infrastructure projects. As these professionals are spread over a vast geographical area and are constantly moving between project sites, an electronic quantitative questionnaire based on questions derived from the literature review and experience of the lead researcher in his role in delivering schools in the province, was deemed the most appropriate method to gather this data.

Research method

The data for this study consists of primary data collected via a quantitative questionnaire and secondary data from online reports and publications sourced from databases. The study was limited to rural government schools in the Eastern Cape Province, South Africa, as these show the highest incidence of schools with an unreliable electrical supply and in addition, the greatest percentage of schools being in rural areas (54%). An enquiry at the Department of Education resulted in contact

being made with a member of the Project Management Team that plays an oversight role on education infrastructure in the province who provided a list of all three implementing agents involved in delivering schools in the province. The primary data was obtained through a questionnaire consisting mainly of 5 point Likert scale type questions emailed to one-hundred and seven architects, quantity surveyors, construction project managers and engineers who have fulfilled a design consulting and principal agent role in the Eastern Cape schools building program. Twenty-eight recipients could not be reached on the contact details provided, in the yellow pages and/or on their websites. Twenty-one returned completed surveys.

Research results

Of the 21 respondents, 20% of the initial sample, 61.9% were Quantity Surveyors, whilst none of the large multi-disciplinary consultancies responded and there were no project management firms in the population. Of these 21, 9 had fulfilled the role of principle agent on projects. Nearly 40% of consultants advised that at least half to all of the schools they have encountered were not electrified.

When reviewing why it was that schools are not electrified, the main reason identified was due to the fact that the community is not electrified with over 60% responding that often to always the lack of electricity in a community was the reason the school is not electrified. Damaged electrical infrastructure ranked second with a mean score of only 2.29 indicating that this is not a major reason why schools are not electrified, although it does highlight a secondary problem with electrical infrastructure in terms of a lack of maintenance to the distribution thereof impacting on the ability of schools to rely on it for power.

Table 1, Main reason why rural schools are not electrified.

Reason	Unsure	Never……Always					Mean Score	Rank
		1	2	3	4	5		
Community not electrified	0,0%	4,8%	23,8%	9,5%	33,3%	28,6%	3.57	1
Damaged electrical infrastructure (school/community)	0,0%	14,3%	38,1%	19,0%	14,3%	4,8%	2.29	2
Building not designed/built with electrical installation i.e. No Distribution Board or wiring	4,8%	19,0%	28,6%	14,3%	19,0%	4,8%	2.19	3
Community electrified but no connection to school	0,0%	33,3%	23,8%	14,3%	14,3%	4,8%	2.05	4
No school buildings or buildings unsafe for electrification	9,5%	33,3%	4,8%	38,1%	0,0%	4,8%	1.81	5
Cost of installation unaffordable	4,8%	38,1%	38,1%	4,8%	0,0%	4,8%	1.53	6

When it came to looking at alternatives to the current challenges in electrifying schools in rural areas, respondents overwhelmingly agreed that solar power can be employed the quickest out of all power supply types for the electrification of rural schools. Over 90% of the respondents either 'agreed' or 'strongly' agreed that solar technology can be employed the quickest with a MS of 4.48.

Table 2, Type of power supply that can be employed quickest for the electrification of rural schools.

Type	Unsure	Strongly disagree……Strongly agree					Mean Score	Rank
		1	2	3	4	5		
Solar power	0,0%	0,0%	4,8%	0,0%	14,3%	76,2%	4.48	1
Eskom/Municipal supply	0,0%	28,6%	4,8%	19,0%	28,6%	9,5%	2.57	2
Wind power	14,3%	19,0%	9,5%	4,8%	28,6%	9,5%	2.14	3
Fossil fuel generators	19,0%	19,0%	14,3%	0,0%	14,3%	19,0%	2.00	4
Fuel cell generators	19,0%	19,0%	19,0%	14,3%	9,5%	4,8%	1.62	5

Furthermore, those surveyed overwhelmingly believed that solar would also be the most effective technology for the electrification of rural schools. Over 80% of the respondents chose that it would be 'effective' with a MS of 4.33, well ahead of wind power with a MS of 3.19

Table 3, Most effective technology for the electrification of rural schools.

Technology	Unsure	Least effective……Most effective					Mean Score	Rank
		1	2	3	4	5		
Solar power	0,0%	0,0%	9,5%	4,8%	28,6%	57,1%	4.33	1
Wind power	4,8%	14,3%	9,5%	4,8%	38,1%	23,8%	3.19	2
Fossil fuel generators	14,3%	28,6%	28,6%	9,5%	9,5%	4,8%	1.76	3
Fuel cell	14,3%	23,8%	38,1%	14,3%	0,0%	4,8%	1.67	4

In addition, two-thirds of those surveyed selected the 'strongly agree' option for solar power when asked for the most suitable solution for the electrification of schools for areas without Eskom / Municipal grid electrification, achieving an MS of 4.58. A similar response was received when participants to the study were asked with the available resources, which is the most suitable alternative energy system for the electrification of schools in rural Eastern Cape, a MS of 4.33 being recorded for Solar Power. Furthermore, respondents were asked which alternative energy systems have the most potential to meet the energy requirements and reduce the energy dependence of schools on grid electricity. Here again the highest ranked alternative energy solutions were both solar based, with Solar power being ranked 1st with a MS of 4.76 and Solar water heaters being ranked 2nd with an MS of 3.57, slightly ahead of Wind Power.

Table 4, Alternative energy solutions with most potential to reduce energy dependence.

Alternative energy system	Unsure	Low……High					Mean Score	Rank
		1	2	3	4	5		
Solar power	0,0%	0,0%	0,0%	0,0%	23,8%	76,2%	4,76	1
Solar water heaters	0,0%	0,0%	9,5%	14,3%	38,1%	28,6%	3,57	2
Wind power	4,8%	4,8%	4,8%	9,5%	33,3%	33,3%	3,43	3
Biogas (schools nutrition & science labs)	14,3%	9,5%	0,0%	14,3%	47,6%	9,5%	2,90	4
Fossil fuel generators	9,5%	28,6%	19,0%	14,3%	14,3%	4,8%	1,91	5

It is notable that three-quarters of respondents believed that Solar power has a high potential to reduce the energy dependence especially when viewed against those who are aware of the 'Regulations relating to minimum uniform norms and standards for public school infrastructure' in which minimum standards relating to energy provision are listed, including that where no grid connection is available, an alternative source of power should be provided. Only 10 out of the 21 were aware of the legislation. Unfortunately no data was collected on how many of those have proposed the use of an alternative power supply solution in there submission documents although they were asked where no grid connection exists did they allow for an alternative/renewal energy solution and only 19% stated that they did 'Often or Always'. 33.3% have been involved in a project with the department where renewable energy systems have been specified as the main electrical source (not necessarily a school project).

When asked their opinion on the importance of electrification in addressing the functional activities of a school within a rural / community environment, a large majority consider electricity very important for most of the school functions with mean scores for all the listed school purposes well above the mid-point value of 3.00.

Table 5, Indicative importance of electricity for the following purposes

School Purpose	Unsure	Not important…….Very important					Mean Score	Rank
		1	2	3	4	5		
Computer/internet connectivity	0,0%	0,0%	0,0%	0,0%	4,8%	95,2%	4,95	1
Audio-visual equipment	0,0%	0,0%	0,0%	0,0%	23,8%	76,2%	4,76	2
Electronic learning aides	0,0%	0,0%	0,0%	14,3%	14,3%	71,4%	4,57	3
Office administration	0,0%	0,0%	4,8%	14,3%	23,8%	57,1%	4,33	4
Library	0,0%	0,0%	0,0%	14,3%	19,0%	61,9%	4,28	5
Science laboratory	0,0%	0,0%	14,3%	14,3%	19,0%	52,4%	4,10	6
Classroom activities	0,0%	0,0%	14,3%	33,3%	28,6%	23,8%	3,62	7
School nutrition	0,0%	9,5%	23,8%	9,5%	23,8%	33,3%	3,47	8

Respondents were then asked whether learners in rural areas are at a disadvantage compared to their urban counterparts for the following information amenities by not having access to such amenities. Although respondents are not necessarily experts in terms of education of learners, they are all professional persons and therefore have a high level of education as well as experience of the environment in which these schools are situated. It is notable that in addition to libraries being considered to be of major importance as an amenity by more than three-quarters of respondents, the majority of the respondents indicated that they consider learners in rural areas to be at a major disadvantage to all the listed amenities due to the isolation with the MS all greater than 3.7.

Table 6, Extent to which geographical isolation of rural schools disadvantages learners compared to their urban counterparts for the following information amenities.

Amenities	Unsure	Minor……Major					Mean Score	Rank
		1	2	3	4	5		
Municipal libraries	4,8%	0,0%	0,0%	4,8%	14,3%	76,2%	4.53	1
Museums	0,0%	0,0%	4,8%	19,0%	28,6%	42,9%	3.96	2
Theatres	0,0%	0,0%	14,3%	14,3%	23,8%	42,9%	3.81	3
Aquariums, zoo's, parks, etc.	0,0%	0,0%	19,0%	14,3%	19,0%	42,9%	3.71	4

Similarly, when then asked to what extent the internet can act as a substitute information source for these, most respondents at least agree that it can substitute for each of the listed resources and that libraries are ranked the highest and that all are ranked with a mean score of greater than 3.00.

Table 7, Extent to which the internet can act as a substitute information source (video tours, images, web lectures, electronic books, etc.) for urban amenities.

Resource	Unsure	Strongly disagree…Strongly agree					Mean Score	Rank
		1	2	3	4	5		
Municipal libraries	0,0%	4,8%	9,5%	14,3%	33,3%	38,1%	3.90	1
Museums	0,0%	9,5%	4,8%	38,1%	23,8%	23,8%	3.48	2
Textbooks	0,0%	9,5%	19,0%	23,8%	9,5%	38,1%	3.47	3
Theatres	0,0%	4,8%	19,0%	33,3%	28,6%	14,3%	3.29	4
Aquariums, zoo's, parks, etc.	0,0%	9,5%	14,3%	47,6%	19,0%	9,5%	3.04	5

Finally, they were then asked for their opinion on whether web resources could improve learning in rural schools with the use of a range of resources all reliant on electricity or an internet connection. Digital learning material (encyclopaedia, educator guides), Digital media streaming (Discovery Channel, National Geographic) and Digital Textbooks were ranked very closely in 1st, 2nd and 3rd place respectively with over 50% of respondents strongly agreeing that Digital Media Streaming could improve learning.

Table 8, Extent to which web resources can improve learning in rural schools with the use of the following resources.

Web resource	Unsure	Strongly disagree....Strongly agree					Mean Score	Rank
		1	2	3	4	5		
Digital learning material (encyclopedia, educator guides, etc)	0,0%	0,0%	9,5%	9,5%	38,1%	42,9%	4,14	1
Digital media streaming (Discovery channel, National Geographic, etc)	0,0%	0,0%	14,3%	9,5%	23,8%	52,4%	4,14	2
Digital textbooks	0,0%	0,0%	9,5%	19,0%	23,8%	47,6%	4,09	3
Web teaching/virtual lessons	4,8%	0,0%	14,3%	9,5%	28,6%	38,1%	3,62	4
Content storage (portals and clouds)	4,8%	4,8%	14,3%	19,0%	19,0%	38,1%	3,57	5

DISCUSSION

According to the October 2014 NEMIS report, there are 23 740 ordinary schools in South Africa: 1 131 of these schools do not have electricity at all. A further 2 773 schools have an unreliable electrical supply. This means just under 5% of the schools in the country are not electrified. Another 11.7% of the schools do not have a reliable electrical supply. The report further provides that in the Eastern Cape Province, which has 5 468 ordinary schools: 377 schools (7%) are not electrified and a further 1 450 have an unreliable electrical supply. However, the data from the survey would appear to suggest that the situation is far worse with over 38% of the respondents putting the percentage of un-electrified schools encountered in the Eastern Cape in the range between 50 – 100%. Over 19% of the respondents indicate that 25 – 50% of the schools they have encountered are not electrified. Although the majority of the schools encountered by these professionals are in rural areas, over 50% of schools in the Eastern Cape are in rural areas and therefore make up the bulk of the 5468 ordinary schools, suggesting that the number of schools encountering problems with respect to a reliable electrical supply is greater than the combined total of 1827 schools deemed to have an unreliable supply.

From the survey, it was established that in areas without grid electricity, alternative energy solutions are not considered in the design scope of schools even though in the South African Schools Act (2013) provision is made that all schools must have some form of power supply and that 'the forms of power supply may include grid electrical reticulation, generators, solar powered energy or wind powered energy sources'. The research shows that solar and wind power would be the most effective and suitable renewable energy system should this be included as an option in the scope of works.

Over 90% of the respondents indicated that solar power can be employed the quickest when compared with other sources (including grid electricity) for the electrification of rural schools. Over 80% of the respondents deemed solar power as either 'effective' or 'most effective' for the electrification of rural schools. Respondents indicated that the main reason why schools are not electrified is due to lack of electricity in the community of the school. All of the respondents supported the notion that learners in rural areas were at a major disadvantage due to isolation from amenities such as libraries, museums, theatres, aquariums, zoo's and parks. In addition, more than half of the respondents claim that more than 75% of the schools they have encountered in the Eastern Cape are rural schools further emphasising the importance of electricity, which is deemed most critical by respondents for computer/internet connectivity. Furthermore, the majority of the respondents indicated that web resources could improve learning in rural schools which are resources dependent on electrical connectivity.

When building new school buildings, in areas without grid electrification, more than half of the respondents confirmed that they specified full reticulation to the new school buildings in anticipation of grid electrification but the majority of the respondents identified budgetary constraints as being the main barriers against the adoption of renewable energy systems in schools. Security considerations (theft of equipment) ranked as the second major barrier to adoption. Over 80% of the respondents deemed solar power as the most suitable alternative energy system for the electrification of schools in rural Eastern Cape.

CONCLUSION

The majority of schools without electricity in South Africa are in the Eastern Cape and more than half of the schools in the province are considered rural schools. Schools and learners outside the urban centres have to travel long distances or into neighbouring provinces to watch a theatrical production, visit a museum, a snake park or an aquarium. Arranged school visits to these information and cultural amenities are an invaluable and essential supplement to their development. The internet has proven to be one of the most valuable information sources and is considered by many as the greatest library. With this resource, one can keep abreast with the latest information and current affairs from the most remote corner of the world. Internet connectivity is essential in any institution of learning. Electricity is a prerequisite for internet connectivity. The amount of data in the form of documents, audio, videos, images, journals, books, documentaries, tours, lectures and guides found on the internet is endless. Companies, non-governmental organisations, research institutions and documentary channels have loaded it with mountains of learning materials which can only be accessed through internet connectivity and the necessary apparatus. The value of seeing a live science experiment, a tour through the pyramid site at Giza or watching a predator catch its prey is taken for granted and should not be undermined. With proper exploitation of the internet, schools in remote rural areas can and should perform on par with their urban counterparts.

It is evident that alternative / and renewable energy systems are not considered in the design scope of school building projects. In areas without electricity, provisions are made to electrify the school only when the grid is expanded to the area. Alternative energy solutions would allow for immediate electrification of virtually all schools and renewable energy systems would enable the immediate electrification in most situations. From the findings, budgetary constraints and security concerns (theft of the equipment) are the main barriers to the adoption of the technology. Solar power has the highest potential to meet the requirements of schools and reduce their grid energy dependence. Two of the main advantages of solar and wind energy are environmental consideration. Solar power

is the most suitable alternative energy system for the electrification of rural schools in the Eastern Cape.

Pupils in remote rural areas are at a distinct disadvantage due to the distance to the closest cultural & learning centres such libraries, museums, theatres, animal parks, aquariums and zoos. Electricity enables internet connectivity and internet connectivity is a necessity in any centre of learning, not least in the administration of the education system. Renewable energy systems would enable the electrification and internet connectivity of rural schools and therefore enhance learning delivery and opportunity for students to gain a thorough education that would enable them to break free from the cycle of poverty they currently exist within.

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EMBEDDING SUSTAINABILITY INTO THE NEW COMPUTER SCIENCE CURRICULUM FOR ENGLISH SCHOOLS

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ABSTRACT

The primary goals of this study are to: embed sustainable concepts of energy consumption into certain part of existing Computer Science curriculum for English schools; investigate how to motivate 7-to-11 year old kids to learn these concepts; promote responsive ICT (Information and Communications Technology) use by these kids in their daily life; raise their awareness of today's ecological challenges. Sustainability-related ICT lessons developed aim to provoke computational thinking and creativity to foster understanding of environmental impact of ICT and positive environmental impact of small changes in user energy consumption behaviour. The importance of including sustainability into the Computer Science curriculum is due to the fact that ICT is both a solution and one of the causes of current world ecological problems. In order to achieve the aforementioned goals, sustainability requirements, curriculum requirements and technical requirements are firstly analysed. Secondly, the web-based user interface is designed. Next, a set of three online lessons (video, slideshow and game) is created for the website GreenICTKids.com taking into account several green design patterns. Finally, the evaluation phase involves the collection of adults' and kids' feedback on the following: user interface; contents; user interaction; impacts on the kids' sustainability awareness and on the kids' behaviour with technologies. In conclusion, a list of research outcomes is as follows: 92% of the adults learnt more about energy consumption; 80% of the kids are motivated to learn about energy consumption and found the website easy to use; 100% of the kids understood the contents and liked website's visual aspect; 100% of the kids will try to apply in their daily life what they learnt through the online lessons.

INTRODUCTION

The year 2011 saw the resurgence of Computing in English schools when the British Computing Society (BCS) helped promote the reintroduction of the Computer Science curriculum in the English schools (Brown et al., 2013). ICT in schools was considered as a "boring" topic, since it mainly focused on the use of Microsoft Office software. This phenomenon is partly explained by the lack of trained ICT teachers in the United Kingdom (BCS Academy of Computing, 2012; Computing at School, 2012). ICT was not considered as a "rigorous academic subject" and children typically could self-teach ICT, thus, ICT was not included in the English high school diploma (BCS Academy of Computing, 2012). Since September 2012, English schools are encouraged to include the new Computer Science curriculum defined by the Department for Education (UK), into their programmes/courses (BCS Academy of Computing, 2012). According to the National Computing curriculum in England, there are four different key stages where students will learn about Computer Science (Department for Education, 2013). Computing at School (CAS) explains that five different disciplines need to be taught through the key stages: "algorithms", "programs", "data", "computers" and "communication and the Internet" (Computing at School, 2012). Resulting from BCS promotion and support for excellence, Computer Science is now considered as an equal topic to Mathematics or Physics. Additionally, CAS currently offers a unique accreditation for teachers of Computer Science, which will give them professional recognition accredited by BCS (BCS Academy of Computing, n.d.). The aim of the new Computer Science curriculum is to help children have a better understanding of the computing world and to appropriately acquire computing related knowledge and skills for their future career (Department for Education, 2013). BCS has stated that by 2015, half a million more ICT professionals will be needed in the United Kingdom (BCS Academy of Computing, 2012). Additionally, the new Computer Science curriculum aims to cultivate applied computational thinking and creativity to help students understand and change the world (Department for Education, 2013). However, in its current state, this curriculum does not include the concept of sustainable development (which means "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987)). The importance of embedding sustainability into the Computer Science curriculum is due to the fact that ICT is "both a solution and the cause of the ecological problem" (Gordon et al., 2014). Thus, it is imperative that the link between sustainable development and Computer Science hardware and software methods is made explicit (Gordon et al., 2014). "Change the world" (Department for Education, 2013) can only happen if sustainability is effectively taught at school and user energy consumption behaviour is changed. UNESCO agency shows that education could help raise awareness of sustainability (Gordon, 2010). Including sustainability within the Computer Science curriculum could also help prepare children for the "green jobs" that are currently available in England (Gordon et al., 2014). The United Kingdom is playing a great role in promoting sustainability issues (Janjua & Mahmood, 2014). Moreover, 54% of the first year students following computing courses in one university are not even aware of the fact that ICT impacts the environment (Gordon, 2010). Besides, there is also a decrease in the enrolment of students in sustainability courses (McIntosh, 2008). Teaching sustainability from early primary days could better prepare students for universities' academic programmes on sustainability, therefore give professors the opportunity to go further and deeper in their teaching (Gordon et al., 2014).

LITERATURE REVIEW

Computer Science curriculum

As previously discussed, it is necessary to reintroduce Computer Science into the English Curriculum (BCS Academy of Computing, 2012). CAS considers that Computer Science is a discipline like Mathematics or History, and therefore should be taught at school (Computing at School, 2012). With the creation of a new Computer Science curriculum, the English Department for Education intends to give the students the resources to understand the world and to be able to contribute to its change (Department for Education, 2013). Indeed, it is important to provide the right type of education to kids so that they will not be "passive consumers of an opaque and mysterious technology" (Computing at School, 2012). The English Department for Education has defined the Computer Science curriculum for each key stage (1 to 4) which corresponds to the age of 5 to 16 years old (Department for Education, 2013). CAS states that these four key stages should take into account five different disciplines: "algorithms", "programs", "data", "computers" and "communication and the Internet" (Computing at School, 2012). Therefore, for each key stage, specific notions for each of these disciplines will be embedded into the computing curriculum (Computing at School, 2012). CAS emphasises that "programming encourages creativity, logical thought, precision and problem-solving". CAS also mentions that programming "helps foster the personal, learning and thinking skills required in the modern school curriculum" (Computing at School, 2012).

Green Curriculum

The English government has identified four different concepts that are among the top priority areas: "sustainable consumption and production", "climate change and energy", "natural resources protection and environmental enhancement" and "sustainable communities" (DEFRA, 2009). In order to embed sustainability into the Computer Science curriculum, the easy part is to identify the sustainable concepts to be embedded (Fox et al., 2009). Many examples of relevant concepts could be embedded in the green curriculum: power usage (Gordon et al., 2014), climate change and energy (Gordon, 2010), eco-efficiency and ecological footprint [13].

It seems that one of the most important aspects of sustainability to be embedded in a Computer Science curriculum is energy consumption. Indeed, computers definitely have strong links with energy consumption (Gordon, 2010). ICT consumes many resources: electricity, equipment and cooling are only few of them (Gordon et al., 2014). Additionally, it is important to progress towards a more environmental sustainable ICT by minimizing the energy consumed in the ICT equipment lifecycle (Ohara & Steven, 2009). It is necessary for a sustainable ICT strategy to focus on reducing energy cost and promoting efficient and responsible use of ICT (Janjua & Mahmood, 2014). Besides, the International Energy Agency (IEA) states that energy growth worldwide will be 33% by 2040 (International Energy Agency, 2015). Even though OECD (Organisation for Economic Co-operation and Development) countries are trying to make energy use more efficient, some developing countries still assume a business as usual (BAU) trend of growth which is unsustainable and consequently, effect a decreasing trend of available natural resources (for example fossil, fuels, et cetera.) (International Energy Agency, 2015). It is therefore, important to understand the critical situation of energy and be able to apply best energy saving practice whenever possible (International Energy Agency, 2015). It is necessary for people to understand energy matters, basics of energy and what it represents, link between energy and the world, followed by adhering to good decision making guidelines (Chen et al., 2013).

The Department of the Environment, Water, Heritage and the Arts of the Australian government explains in its sustainability curriculum framework that it is relevant to gradually teach children from the age of 3 to the age of 12, the different notions: energy use at home/school, energy systems, climate change, different sources of energy, ways of saving energy, consequences of energy choices on the environment and measuring and metering energy consumption (The Department of the Environment, Water, Heritage and the Arts, 2013).

Finally, Lee et al. (2013) show that students in one secondary school could apply knowledge on green buildings in their own homes after having undergone a course on energy saving related topics.

Pedagogy

A challenge is to motivate students and professors to learn about sustainability and apply sustainability-related practices in their daily life (Fox et al., 2009; Penzenstadler & Fleischmann, 2011). It is imperative that teachers are aware of sustainability (Fien, 2001) and students could see how sustainability matters to teachers who are considered as their role models (Penzenstadler & Fleischmann, 2011). Another challenge that arises is a direct embedment of sustainability concepts into existing materials which could ensure that students will stay motivated and yet fail to apply what they have learned, or creating new materials which help raise awareness of sustainability but may discourage students to learn about it (Gordon, 2010). Fien (2001) defines four important questions regarding education for sustainability: “does it matter to me?”, “should I do something about it?”, “how can I do something about it?” and “what will I do?”.

In order to motivate students to learn about it, sustainability should be linked with individual professional development (Gordon et al., 2014), where concrete examples of daily life should be given (Fien, 2001), the contents should be contextualised (Gordon et al., 2014) and concrete facts as well as pictures representing bad effects of non responsible use of ICT should be shown to the students (Gordon, 2010).

In order to capture the attention of students, lessons should be student-centered and should generally consist of experiential activities where active learning is the key to motivating the students (Fien, 2001). Students will better understand sustainability through experimental as well as experiential learning activities and educational games because these approaches will help capture their attention (Seager & Selinger, 2009). Computer games can make education more fun, better engage students and consequently, get them more interested (Chen et al., 2013). A report from The Royal Society (2012) and the curriculum created by CAS (Computing at School, 2012) also suggest to teach programming to kids with visual tools with colours and animations (Kodu or Scratch for example).

Finally, the use of a video to provide environmental education has been shown very effective for secondary schools. It helped to describe and explain things that could not be explained through traditional learning materials (textbooks). Moreover, traditional materials sometimes result in an inability to apply the acquired knowledge in real life examples. Therefore, a video could help represent real world situations and problems. It could be attractive to students, capture their attention, create anticipation and increase retention. Teaching actively with materials such as videos makes students become real actors who are not mere spectators of knowledge and are more confident to change which thus gives them a feeling of empowerment. (Roy et al., 2012)

Household Energy Consumption in the UK

Different sources show different numbers for the typical average energy consumption per English household. Statista (n.d.) shows that the average English household consumed 3567 kWh in 2011, up to 4400 kWh for some houses. On the other hand, British Gas shows an average of 1150 kWh per household for 3 months (from December 2010 to February 2011), which represents 4600 kWh for one year (The Guardian, 2011). British Gas gives numbers that differ from one area to another one: the average energy consumption per household is the smallest in London, while in Truro it is the biggest (The Guardian, 2011).

Worldbank (2014) also shows a different figure for the United Kingdom: around 5400 kWh per household in the year 2013. It is important to note that the average energy consumption per English household is decreasing.

Finally, the Department for Environment, Food and Rural Affairs (DEFRA) provides an Excel file to analyse the energy consumption per household per year. Moreover, this document reveals the energy consumed by household sorted by usage (electronic devices or heating systems for example). According to DEFRA (n.d.), an English household consumes 4100 kWh per year.
These data are important for this research because they are fed into the contents for Lesson 3 of the website GreenICTKids.com.

METHODOLOGY

Requirements Analysis

Sustainability Requirements
Related work has shown that the most important sustainable concept to embed is about energy (DEFRA, 2009; Gordon et al., 2014; Gordon, 2010; The Department of the Environment, Water, Heritage and the Arts, 2013). Besides, the ecological problem derives partly from energy consumption and ICT (Gordon et al., 2014). Therefore, it is also relevant to include the concept of climate change in the online lessons that the author has created (DEFRA, 2009; Gordon, 2010).

Related work shows that it is necessary to teach kids the fundamentals about energy consumption (Chen et al., 2013; The Department of the Environment, Water, Heritage and the Arts, 2013). It is also relevant to briefly introduce the concept of global warming and greenhouse gases (GHG) emissions (The Department of the Environment, Water, Heritage and the Arts, 2013), in order to prepare them for understanding of today's problems and to appropriately address ecological challenges. Besides, when it comes to energy consumption, it is really necessary to educate kids about good practices they should adopt when using different electronic devices in their everyday life (Department for Education, 2013).

Of course, many other sustainable concepts could be embedded into the Computer Science curriculum such as water usage, food wastage or equipment recycling (The Department of the Environment, Water, Heritage and the Arts, 2013). These have not been included in the GreenICTKids online materials because they are less relevant to the curriculum requirements that will be discussed in the next part.

Curriculum Requirements:
It is firstly necessary to specify at which key stage the sustainability requirements previously identified could be embedded in. Since these sustainability requirements are mainly about energy consumption, good practices with electronic devices and climate change, it seems that embedding these concepts at the first key stage (in other words from 5 to 7 years old) is rather premature.

However, during the second key stage (from 7 to 11 years old), the students need to learn about computer components and communications through the Internet (Computing at School, 2012; Department for Education, 2013). They will already have acquired an advanced knowledge of using the Internet and technologies in general as well as the basis to understand the way programs work on a computer and how an operating system operates (Computing at School, 2012; Department for Education, 2013). It seems then that it is necessary to include the sustainability requirements at this key stage, in order for the kids to become familiar as early as possible with energy consumption while learning about electronic devices in general.

Technical Requirements:
Regarding sustainability requirements, the curriculum requirements and pedagogical aspects that are covered in the literature review, the author has chosen to create a website with a set of different lessons to embed the identified sustainable concepts. Therefore, it complements the existing Computer Science curriculum and could be appropriately integrated by relevant school teachers. It is an auxiliary material that has been created and schools can use it in addition to the materials they already have. The website comprises a set of three lessons: a video, a slideshow and a game.

Design of the Online Lessons

Definition of the Contents:
This website firstly aims to give an introduction to energy and to explain why energy is important in general, followed by providing more detailed energy-related information about electronic devices, computer components and common usages of computer. Finally, users are given the opportunity to play with what they have learned in order to become more familiar with the concept of energy and are also given an insight into a more sustainable energy consumption at home.

The website GreenICTKids aims to help kids gradually progress through the contents about sustainability via a series of lessons. These concepts have been identified and extracted from existing literature by the author. Subsequently, these concepts are appropriately embedded into the current Computer Science curriculum.

This research has identified that for pedagogical reasons, creating a video and a game are alternative ways to make learning fun with the aim of inducing positive impact on their behaviour (Chen et al., 2013; Computing at School, 2012; Fien, 2001; Roy et al., 2012; Seager & Selinger, 2009; The Royal Society, 2012). The slideshow that the author has created helps convey fundamental knowledge that would be too tedious to describe in the video. Besides, some kids may have been aware of energy consumption relating to electronic devices (or usage) and therefore, kids may appreciate the ability to select a particular device (or usage) they are interested in.

Web Development Technologies:
The languages HTML5 and CSS3 have been used to develop the website. In order to create the quizzes and animations in the webpages, the language JavaScript has been used and particularly the jQuery library. Lightbox, a library of JavaScript, has been used to create the slideshow. The libraries jQuery, jQuery UI and jQuery Alert have been used to create the game.

Video Producing and Image Editing Tools:
In order to create the video for Lesson 1, the software Final Cut Pro X (FCPX) has been used, running on Mac OS X Yosemite. To create all the images for the website, such as the logo, the thumbnails of Lesson 2 and the different slides that constitute Lesson 2, the software Affinity Photo has been used, also running on Mac OS X Yosemite.

Green Design Patterns:
Greenspector (n.d.) emphasises that it is important to follow green design patterns when developing for the web, in order to minimize the energy consumed by the website (Green Code Lab Challenge, 2014). The green design patterns can be applied at different levels: the development of the website and the web hosting platform. Respecting criteria of web usability also helps optimise the website.

- Website Development:

All the pictures have been compressed, in PNG or JPG format, depending on the type of picture. If the picture contains mainly text, PNG format is more appropriate to compress. On the contrary, if the picture contains more graphic contents with many colours, JPG format is better. The image quality has been set to 95% for the JPG pictures with Affinity Photo. GTmetrix.com provided an optimized version of each picture (lossless compression). Finally, using TinyPNG.com, all optimized versions have been recompressed again to get the smallest possible size without compromising too much image quality. The fully compressed pictures therefore help speed the loading of the pages and reduce the energy consumed while accessing the pages.

The JavaScript and CSS files are separated from the HTML files. This decreases the loading time and makes the code cleaner. Besides, the JavaScript files are called at the end of the HTML pages so that they will be loaded only once the HTML content is loaded. The CSS files are in the head of the HTML document, otherwise the HTML content would sometimes load without the correct style or the correct style would be applied too late. All frequently used JavaScript files have been gathered and minimized into one JavaScript file. The same goes for the CSS files. This helps reduce their size, decrease loading time and reduce the number of HTTP requests from client to server. Indeed, having only one or two files to download requires fewer requests than having ten files to download. Thus, this optimizes the loading time and response time which reduces energy consumption.

- Hosting Solution:

The author decided to use a caching policy of one year on the web browser: after the first access, the web browser will not need to again download the pictures, CSS and JavaScript files for one year. The HTML is cached for a shorter period of time. This reduces the loading time and the energy consumed in general.

The website GreenICTKids.com is hosted on a 100% powered by renewable energy platform: iPage.com.

The Content Delivery Network (CDN) Akamai is used to replicate a particular set of data all around the world and minimizing the requests to original servers in Boston. This reduces the loading time and the energy consumption.

- Web Usability:

Attempts have been made to make the website responsive on mobile phones and tablets. The menu and categories are responsive on smaller devices. Lesson 2 is responsive. The embedded video in Lesson 1 is also responsive. Lesson 3, however, does not support drag and drop on tactile devices.

Colours, font and images are basic and do not alter the user experience. If a client cannot display the text in the font “Helvetica”, the font “Arial” will then be used.

Web usability is important because if the website is difficult to use, the clients would spend more time trying to view the contents, thus consuming more energy.

Implementation of the solution

Website:
The author has modified a template based on the Bootstrap framework. The languages used are HTML5 and CSS3. All animations have been created using jQuery, a JavaScript library. The general contents of the website are colourful in order to attract the attention of kids and to make it more appealing.

Lesson 1, the Video:
The first part of the implementation is Lesson 1, where a video has been created as a means of introducing energy consumption to the kids. Before creating the video, the author wrote the script of the video and collected all relevant sustainable notions to be embedded in the video. In order to produce the video, the author used different free video clips and pictures from the Internet. The video has been created with the software FCPX. The audio part of the video is directly imported from the audio libraries of FCPX. The video has been produced in 1080p (full HD resolution) at 24 frames per second (cinema standard). Due to features, as well as convenience and accessibility reasons, the video has been uploaded on YouTube. This made it easy to embed and to be responsive on the webpage. YouTube also helps GreenICTKids’ video to be more visible on the Internet. Thus, the website is potentially more likely to be visited by kids or schools. The sustainability-related facts used in the video have been taken from a broad variety of sources on the Internet.

Lesson 2, the Slideshow:
The second part of the implementation is Lesson 2, which consists of a slideshow of pictures describing energy consumption related to different forms of usage, electronic devices and computer components, as well as their definitions. The slides and thumbnails have all been created with the software Affinity Photo. Some of them have been saved in the PNG or JPG format. The choice of a particular format depends on the type of pictures, number of colours per picture and amount of text. All the pictures have been recompressed thanks to the website GTMetrix.com which gave an optimized version of each picture, and then each of these optimized versions have been compressed again with TinyPNG.com, to occupy as less space as possible on the webpages. The slideshow has been embedded in the website with the use of Lightbox and animation capability of jQuery. All the information about energy consumption of the devices, the computer components and the different forms of usage come from different online sources. Clicking on the thumbnails

which represent each slide reveals the picture with definition, goal and power consumption of the desired device or usage.

Lesson 3, the Game:
This part describes the implementation of the final lesson, Lesson 3, which consists of a game with a drag and drop mechanism. Here, kids need to drag items from the shop and drop them in the house after specifying their usage duration. They will then be able to see the total of their energy consumption of the day which cannot exceed a prescribed threshold. This drag and drop mechanism is facilitated with the use of jQuery and some other related libraries such as jQuery UI and jQuery Alert. This research has defined a limit of energy consumption that should not be exceeded in the game. Indeed, it is necessary to be more sustainable and to understand the need of gradually reducing the energy consumed every day. The literature review concerning the energy consumed in the United Kingdom, which has shown that the current trend is to decrease the general energy consumed in each UK household (DEFRA, n.d.; Worldbank, 2014), permits the author to determine that ICT appliances represent on average 20% of the energy consumed by a UK household. The DEFRA (n.d.) documents have identified a decrease in the energy consumption every year between 2008 (4653 kWh in average) and 2014 (4115 kWh in average). In order to continue to be more sustainable, it seems relevant to assume that an average energy consumption of 4000 kWh per year would be a good target. It would represent around 11 kWh per day. As mentioned, ICT appliances represent around 20% of the daily energy consumption, therefore ICT appliances would consume around 2.2 kWh per day. The threshold of Lesson 3 is set to 2.2 kWh per day of energy allowed for the ICT equipment available in the game. Therefore, if kids do consume more than the limit of 2.2 kWh a day, the game will ask them to be restarted.

Quizzes 1 and 2:
The final part of the implementation explains how the two quizzes have been implemented in the website and which technologies have been used. The two quizzes are based on an existing example of quiz from Jeremy Rue. They are developed using JavaScript. The style of the quizzes is defined by a CSS file. It is important to note that both quizzes have their own JavaScript file and each JavaScript file contains questions that the kids are asked. Both quizzes are directly linked to the lessons. Quiz 1 is naturally linked with Lesson 1 and the same goes for Quiz 2 and Lesson 2. Both quizzes contain relevant questions concerning both lessons, and are a means for kids to self-assess their knowledge and understanding of Lessons 1 and 2.

Design of the Tools for the Evaluation

Two Google forms have been created to collect feedback about the website from the adults and kids. The following subparts describe how the questionnaires for adults and kids have been designed.

Design of the Questionnaire for Adults:
This questionnaire is targeted at adults who have gone through the lessons and quizzes in the GreenICTKids website. The questionnaire for adults focuses on three different domains: usability, motivation of children and impact on children. Each area has a corresponding set of questions. To obtain quantitative data, the questions have been formulated in the form of declarative sentences and the adults are supposed to choose an answer from the following set of possible responses: “strongly agree”, “agree”, “neutral”, “disagree” and “strongly disagree”. One optional open question has also been asked.

Design of the Questionnaire for Kids:
This questionnaire is targeted at kids who have gone through the lessons and quizzes in the GreenICTKids website. The questionnaire for kids also focuses on the three different domains previously mentioned. However, the questions have been differently phrased. A majority of the questions require a "Yes" or "No" response while the rest offer a simple multiple question with two or three options. An open question has been asked too. Two additional questions are also asked to provide insight into the kids' performances in the two quizzes.

RESULTS AND DISCUSSION

13 adults have answered the questionnaire for adults. Among them, 3 have answered the optional open question. 5 kids have answered the questionnaire for kids. Therefore, it cannot represent the majority of kids in the United Kingdom. It was more difficult to find kids to respond to their questionnaire due to several factors: kids need to understand English, kids need to be between 7 and 11 years old and the parents need to agree to show the website to their own children. Despite the small number of respondents, a pattern among the answers can be clearly identified.

The results of this research show that the website GreenICTKids.com has content that can motivate kids to learn about sustainability and energy consumption, as well as applying their newly acquired knowledge in their daily life. Indeed, 100% of the kids will try to apply in their daily life what they have learnt through the three lessons and 80% of the kids are willing to learn more about energy and sustainability in general. Besides, 100% of the kids liked the visual aspects of the website. Both adults and kids declared the website is easy to use and navigating between sections is easy.

According to the results collected from the kids, although 60% of the kids had prior knowledge about energy consumption and sustainability, 100% of the young respondents have understood the lessons and quizzes in general. It is therefore interesting to note that the adults expected less of children regarding their understanding of the material (77% of adults think quiz questions are easy to understand for kids if they have gone through the lessons and only 69% of adults think lessons are easy to follow without prior knowledge in sustainability). In general, the kids have been challenged by the quiz questions.

Another interesting point to note is that 85% of the adults think the kids will be more aware of their energy consumption at home, but only 60% of the kids declared that it is now easier to figure out how much energy they consume at home.

Finally, these results show that the approaches suggested by the literature review, such as teaching with a video, visual contents and learning through playing are efficient and can have a positive impact on students. In particular, the results collected from both adults and kids reveal that children are more interested by the game in Lesson 3 and by the video in Lesson 1 than by the slideshow in Lesson 2. The results collected from the adults also emphasise that the video can have a positive impact on the kids' behaviour.

CONCLUSION AND FUTURE WORK

In summary, the results of this research show that kids were motivated by the website GreenICTKids.com to learn about energy consumption and about sustainability in general. The most important objective of this research was to have a positive sustainable impact on kids' behaviour and according to the analysis of the results, all the kids will try to apply their newly acquired knowledge in their daily life. Through the video, the slideshow and the game, while learning about computer components, about the usage of computers and the electronic devices they have at home, the kids learnt the fundamentals of energy and power consumption. In addition to this, they have been introduced to the notions of climate change, global warming and greenhouses gases, which are key factors in the understanding of the ecological challenges of today's world.

These pedagogical approaches are student-centered and differ from the traditional textbooks and teacher-centered lessons. Visual materials such as video and slideshow helped to motivate kids to learn about energy. Interactive material such as drag and drop game helped to involve kids in learning about energy consumption of their electronic devices. The kids who participated in the study were able to learn more about sustainability while having fun but being challenged by quiz questions as well and are now better equipped for their potential future studies in ICT and in sustainability. This research shows that it is possible to embed sustainability into the Computer Science curriculum and to create an impact on students' behaviours. This also helps to prepare students for "green jobs" in England.

As future work, in order to make the website even more attractive and appealing, it may be interesting to improve the quality of the game in Lesson 3 for example by implementing some visual indicators of energy consumption, adding new features, options and items and creating a 3D visualisation of the shop and the house.

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EVALUATING THE EFFECTIVENESS OF CONCURRENT WEB-BASED ENGINEERING AND TECHNOLOGY CURRICULUM FOR RURAL HIGH SCHOOLS

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ABSTRACT

Rural high schools have traditionally lacked access to the most up-to-date engineering and technology curriculum and teaching resources. Recently, the use of communication technology has allowed improved access to learning resources where they would otherwise not be available. With relatively standard technology and limited travel requirements, recent developments have enabled changes to curriculum delivery that should not only provide materials but significantly improve the learning experience. However, the effectiveness of these new media and teaching practices, and their ability to meet learning outcomes, remains largely unanswered.

In order to evaluate the effectiveness of a web-based technology education program Southern Utah University Department of Engineering and Technology developed a pilot program. The course was taught using three different curriculum delivery methods. The first delivery method was the traditional face-to-face classroom setting. The second curriculum delivery method was a hybrid format. The third method was purely online. There were three main objectives to the pilot program. The first was to deliver the same curriculum using three different delivery methods. The second objective was to compare the results of the three delivery methods using the Rubric for Assessing Interactive Qualities (RAIQ) Rubric and Final Grade. RIAQ Rubric was reviewed from five different perspectives; the students in the class, students external to the class, instructors, instructional designers and administrators. The third objective was to determine if the data collected from the different instruments provided conclusive evidence of an effective course.

INTRODUCTION

Engineering and technology programs in rural high schools have always struggled (Howley *et al.*, 2012). Some of the main challenges are discussed below. There are several barriers to delivery of appropriate technology and engineering content in rural high schools. One barrier is the small numbers of students available for recruitment into engineering and technology programs. Another challenge for rural educators includes the breadth of their teaching loads. It is not uncommon to find educators delivering five different subjects (Howley *et al.,* 2012). With such teaching loads, it is difficult to maintain a level of expertise or certification for all subject areas. Additionally, the cost for maintaining a technology lab and keeping a certified instructor can be prohibitive, especially when considering the small size of many rural technology programs. Such challenges can prevent high school students from having the same engineering and technology learning opportunities that are provided in more densely populated urban areas.

In order to address the unique needs of rural high schools, SUU (Southern Utah University) piloted a web-based engineering and technology course. The course was offered as a concurrent enrollment course. Concurrent enrollment courses are when a high school student can receive both college and high school credit for the course. The course was taught using the traditional face-to-face format, hybrid and online course delivery methods.

The curriculum used for the three different delivery methods was the same curriculum. The curriculum is organized and accessed through the Canvas LMS. The curriculum provides remote access to the professor for via email and Gotomeeting multimedia video conferencing. This novel program now offers students in rural high schools similar engineering and technology learning opportunities as students in larger metropolitan areas.

Overview of this Research

This research started with the publication of the first CATIA V5 (Computer Aided Three Dimensional Interactive Application). The CATIA V5 Workbook was first developed in 2001. CATIA V5 is software used in the design work in the automotive industry as well as the aerospace industry. The first web-based CATIA V5 Workbook Website was published in the year 2003. Data regarding the effectiveness of these workbooks in improving student learning has been collected for 14 years. The lessons learned from this data has been applied to the university engineering and technology curriculum at SUU and has been used in schools across the state of Utah. The following information provides a more detailed outline of each research phase.

Phase I

The original research on web-based engineering and technology curriculum started in 2001 with the publication of the CATIA V5 Workbook. The motivation was to provide more CATIA V5 solid modeling training to practitioners around the world remotely, eliminating the cost of time and travel while increasing the knowledge and skills of educators. This prompted the development of the CATIA V5 Workbook website, which at one time had up to 2,000 subscribers from around the world. Data was collected from the subscribers which were used to make improvements to the website and content.

Phase II

The data obtained in the initial research phase was applied to the engineering and technology curriculum at SUU. Additionally, SUU offered concurrent college credit to high schools within the region. A majority of the region consisted of small rural high schools in which engineering and technology programs were in jeopardy of being shut down (Means *et al.,*2014). To promote the growth of engineering and technology curriculum, the State of Utah Education System provided an opportunity for grant aid in the development of STEM (Science Technology Engineering and Mathematics) curriculum. The grant was called TICE (Technology Intensive Concurrent Enrollment). SUU took the lead on this grant opportunity by leading a state-wide team to develop a web-based engineering and technology curriculum. Data obtained in Phase I of the research was coupled with the concepts from the Quality Matters (QM) (Butcher & Wilson-Strydom, 2012). Collectively, this provided the theoretical framework Community of Inquiry (reference Literature Review). The course was titled Introduction to Engineering and Technical Design (IETD) and was developed during the 2012-2013 academic year.

Phase III

The IETD course was piloted by 13 different high schools across the state of Utah during the 2013-2014 academic year. The pilot consisted of three different delivery methods, as shown in Table 1.

Table 1:

Delivery Method	Number of Schools
High school instructor	10
High school instructor led with support by SUU Faculty (using GoToMeeting)	2
Online Independent	1

The updated course was available across the state of Utah in the 2014 Fall Semester, where 26 different high schools taught the IEDT curriculum. Again, data was collected from these courses and used to improve it in the next phase.

Phase IV

This paper focuses on phase IV. The details are presented in the literature review, research method and data analysis,

Contributions of this Research

The contribution of this research could help preserve the existing engineering and technology programs in rural high schools. This research could also provide the avenue to developing new programs. This Utah-specific data could be extrapolated nationally, with many remote schools throughout the nation benefitting from these findings (Cozzens, 2013). Specifically, this research focuses on the following objectives:

1. Deliver the same curriculum using three different delivery methods.

2. Compare the results of the three delivery methods using RIAQ Rubric as the evaluation instruments. The RIAQ Rubric is discussed in detail in the methods section.

3. Determine if the data collected from the RIAQ Rubric provided conclusive evidence of an effective course.

Summary of the Research History

On a much larger scale, the contribution of this research could not only help preserve the existing engineering and technology programs in the state of Utah, but provide the avenue to starting new programs, particularly in rural high schools. There are numerous rural schools throughout the nation that could benefit from these findings especially with the dwindling resources.

LITERATURE REVIEW AND IMPLEMENTATION OF THEORY INTO CURRICULUM

Because web-based education was such a newly emerging educational platform in the early stages of this project, identifying and implementing the best standards for web-based teaching and learning was a critical component to the success of this project. The educational frameworks used in developing the curriculum for TICE were the "Ten Steps to Effective Web-Based Learning" (Cook & Dupras , 2004), a variation of Quality Matters (Butcher & Wilson-Strydom, 2012) and Khans E-Learning Framework (Kahn, n.d.). Collectively, these accepted standards were used to gauge the quality of the curriculum.

The focus of the current research phase has shifted from frameworks and standards to evaluation of the student-teacher interaction. Feedback is obtained from the students, instructors and stakeholders. Because of this shift, a review of the literature surrounding learning styles and strategies is in order. According to Harriman (2011), the key to designing curriculum that best promotes learning involves assuring that the instruction and the delivery mechanism congruently meet the needs of the student. Before being able to meet the needs of the students, the instructor must know and understand student needs. Because there are many various learning styles, the TICE curriculum has implemented a free and easily accessible survey known as the Visual, Aural, Reading & Writing, Kinesthetic (VARK) assessment tool (Cherry, 2014).

The curriculum has also incorporated the Community of Enquiry Framework by which students' transition from passive learning to empowered, active learning by which they produce inspired work. An effective course requires the learners to be engaged and active in the learning process and incorporating this theory into the curriculum will help facilitate the effectiveness of the course (Garrison, 2007).

Tawfeek stated that students sometimes feel isolated and cannot work without constant guidance (Tawfeek, 2014). Tawfeek also stated that a majority of online students need to be extrinsically motivated. In face-to-face classes, the direct interaction with the instructor and consistent assignments are generally enough to motivate students. Everson (2009) developed a community of learners to help provide them with opportunities to learn from each other, share their findings, and

become involved with their fellow students. A sense of community is more likely to motivate students to succeed.

From the literature review, it becomes clear that online courses will not provide a successful learning platform for every student. Because learning styles vary widely, it is critical to know and understand what the student is bringing to the class in the form of foundational knowledge, learning skills, and learning style of each individual to determine whether online learning will be successful. It has been explained, "To succeed in autonomous online learning environments, it helps to be a highly motivated, self-regulated learner" (Artino, 2009).

Massey's (2014) research for Cengage Learning showed that students using online and digital content improved their academic performance by 52%. The same research showed that the students were also significantly more engaged because of the content included in the course.

These are main theoretical concepts that have been implemented into the IEDT curriculum based on the literature review. There are many studies that discuss the importance of online curriculum standards, such as Khans Framework and QM's scoring rubric. The gap in the existing literature is how to apply this quality to the theory of the Community of Enquiry (Garrison, 2007) to make the course effective in the context of engineering and technology curriculum. This is why the students' motivation, background and opinion is so critical.

METHODOLOGY

The Research Method

Action research was the research methodology used. Action Research is specific to education and learning using web-based technology and applying it to the engineering and technology curriculum. Action Research is a powerful tool in stimulating social change and exploring how to modify a situation or practice. Ferrance's (2000) definition of Action Research is, "It is a reflective process that allows for inquiry and discussion as components of the "research."

The Research Process

In the Fall Semester of 2015 one face-to-face class, one hybrid class and one online class was taught via SUU. The curriculum used for all three courses was the IEDT curriculum. The course was organized and accessed through the Canvas LMS. The delivery method and number of students in each class is listed in Table 2. There is a significant difference between the number of students in the Face-to-Face class compared to the Hybrid and Online class. These small numbers are used in this research because they represent the real numbers faced by the rural schools.

Table 2: Delivery method and number of students

Delivery Method	Number of Schools
Traditional Face-to-Face	26
Hybrid	6
Online Independent	3

Note: There is a big difference between the students in the face-to-face class and the hybrid and online class. As mentioned this is one of the challenges facing the rural high schools. This is representative of the real numbers facing the rural high schools.

The instruments used to evaluate the effectiveness of the courses was the RAIQ Rubric and the Final Grade. These classes were located in different remote areas of rural Utah. The distance between the different classes made it difficult to capture the presentation on all ten modules in the curriculum. Due to this limitations one module was selected to represent the other modules. The module selected was Module 5. The Module 5 presentation was videotaped from three different angles; the students computer screen, behind the class and in front of the class. All three videos were combined and synchronized into one video. The purpose for recording three different angles was to capture the interaction taking place during the presentation. Prior to presentation the students took the Module 5 pre-test. Following the presentation and completing the exercises the students took the Module 5 post-test. After all three classes completed Module 5 and the recordings of all three classes were synchronized and produced. The select group of students in the class, students external to the class, instructors and administrators were asked to observe a recorded module presentation. The observers were then asked to complete the RAIQ Rubric evaluating the interactive and effective qualities of the presentation. A sample of the RAIQ Rubric can be viewed in Appendix A as well as a brief description and how it is used (scored). At the end of course the Final Grade was collected as a different instrument to help determine the overall effectiveness of the three different curriculum delivery methods. The data from the RIAQ Rubric and the Final Grade were then compared to determine the effectiveness of the different curriculum delivery methods in the context to engineering and technology.

COLLECTED DATA

The focus of this research was to define what makes effective engineering and technology curriculum and determine how it can efficiently be delivered to rural high schools. The reason this is important is as Badjou & Dahmani , (n.d.) stated "…the need to develop online science and engineering programs is both pressing and crucial." Even though it is pressing and critical, it needs to be effective, it needs to have the components and factors that make it effective, and how to implement it in the most effective manner. The IEDT curriculum has already received the quality stamp from Southern Utah University Online Quality Review Board using a variation on QM Rubric.

Charts 1, 2 and 3 are scored on a scale of 0-5 with 5 being the highest. Element 1=Social/rapport, Element 2=Instructional Design, Element 3=Interactivity of Technology Resources, Element 4=Evidence of Learner Engagement, Element 5=Evidence of Instructor Engagement. For more details on the RAIQ Rubric reference Appendix A. The observers for completing the RAIQ Rubric shown in Chart 1, 2 and 3 were: instructors, administrators, instructional designers, students in the class, and external students. Students in the class correspond to students that actually took the class and completed Module 5. The external students were volunteers that were external to the class. These students did not experience any portion of the class, module, or different delivery methods.

RAIQ Data from the Face-to-Face Course

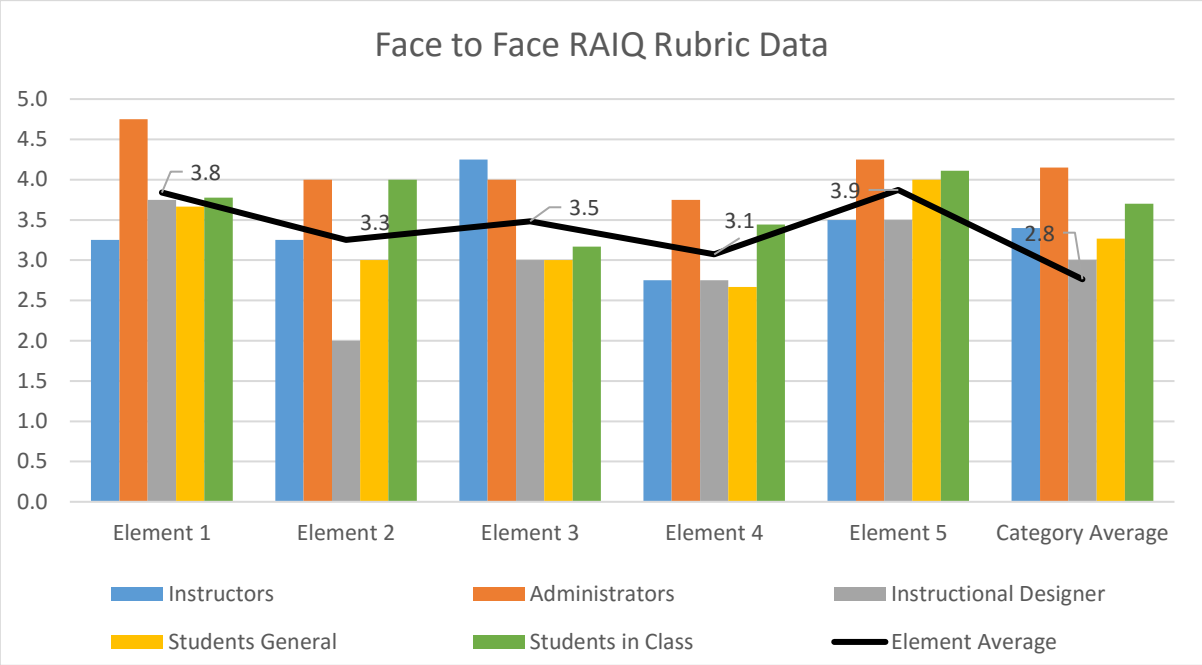

Chart 1 RAIQ data from the Face-to-Face curriculum delivery method

Results

The data shows that those students who experienced the delivery method were much more engaged than the external students (in terms of both their self-reported thoughts and the observations made by the observers). In fact, the students in the class were more engaged than every other group, except for the administrators. The data indicates that the administrators favored the face-to-face curriculum delivery method. They also show that the instructional designers were the most critical of the engagement level for the face-to-face class. The instructors were also somewhat critical about the level of engagement in the face-to-face class, or possibly this presentation specifically. The instructors seemed to be appreciative of Element 3 (Interactivity of technology resources). This makes sense because in another survey four of the five instructors marked "technology" as a critical aid in teaching engineering and technology classes. The same ratio of instructors, in the same survey, marked that they were favorably inclined toward learning and using new technology. It is interesting that the instructional designers assigned a very low interaction score for Element 2 (Instructional designs for interaction).

RAIQ Data from the Hybrid Course

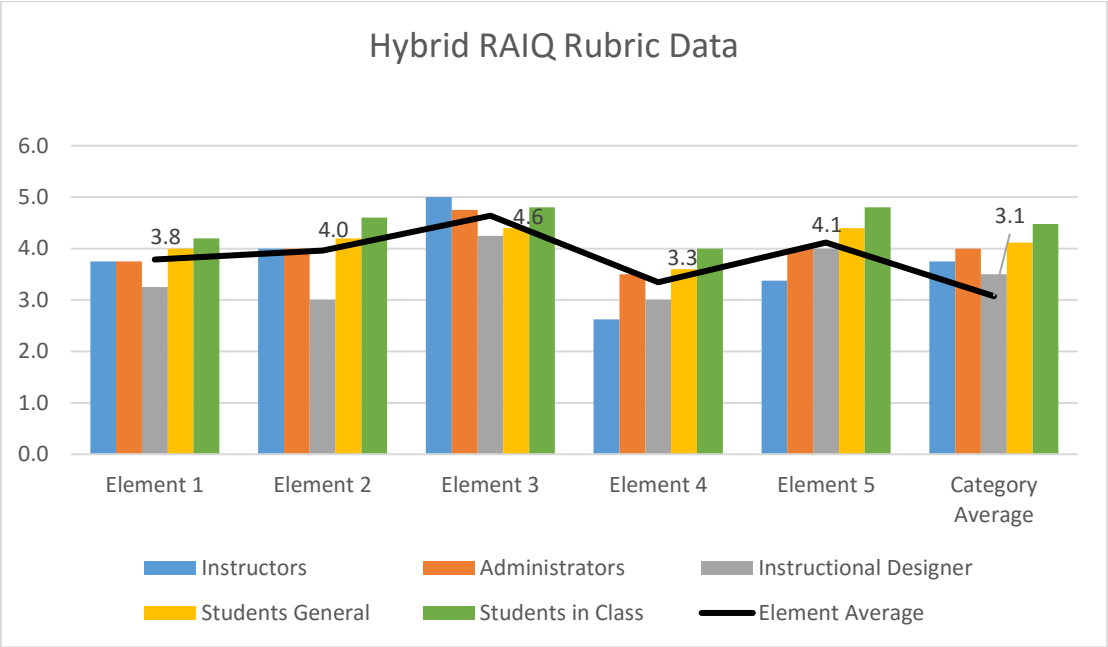

Chart 2 RAIQ data from the Hybrid curriculum delivery method

Results

The students in the class scored higher on engagement during the presentation than any other group; the engagement scores of the other groups (instructors, administrators, instructional designers, and external students), which were assigned by the observers and based on their own self-reports, were all lower. This suggests that a higher level of engagement existed than could be observed from the videos, even with three different camera angles.

The data included in Chart 5 are in accordance with those in Chart 4 (i.e., students taking the class were more engaged than the other participants). More significant is that the students that experienced the class were more engaged than the students in the external group. Overall, the hybrid course scored higher in terms of engagement than the face-to-face course (note the category average). The only area in which the hybrid course did not received higher scores than the other delivery methods was Element 5 (Evidence of instructor engagement).

The instructional designers were the most critical of this curriculum delivery method. The only exception was for Element 5. The instructor group favored Element 3 for this curriculum delivery method. The administrator group was not as favorable toward the hybrid delivery method as they were toward the face-to-face delivery method, but they did maintain the average.

RAIQ Data from the Online Course

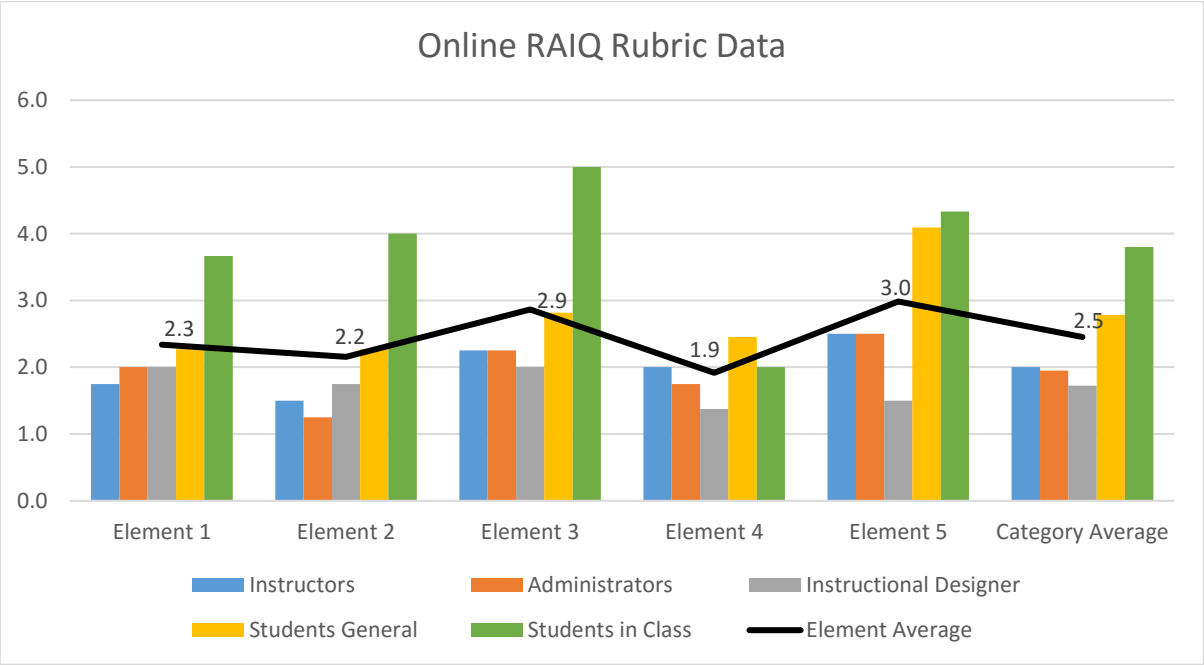

Chart 3 RAIQ data from the Online curriculum delivery method

Results

According to Chart 6, students taking the class were observed to be more engaged than any other group (with no exceptions); otherwise, this curriculum delivery method received the lowest overall scores on the RAIQ. Indeed, this delivery method was observed to be the least engaging of the three.

Final Grades

Face-to-Face Class	Final Grade	points	Hybrid Class	Final Grade	Points	Online Class	Final Grade	Points
Student 1	A-	3.7	Student 1	A-	3.7	Student 1	A	4.0
Student 2	A-	3.7	student 2	A	4.0	Student 2	A	4.0
Student 3	A	4.0	student 3	B+	3.0	Student 3	A	4.0
Student 4	A	4.0	student 4	C	1.7			
Student 5	A-	3.7	student 5	A	4.0			
Student 6	B+	3.0	student 6	A	4.0			
Student 7	A	4.0						
Student 8	A-	3.7						
Student 9	A-	3.7						
Student 10	A	4.0						
Student 11	B-	2.3						
Student 12	A	4.0						
Student 13	A	4.0						
Student 14	B+	3.0						
Student 15	C+	2.0						

Student 16	B+	3.0						
Student 17	B+	3.0						
Student 18	A	4.0						
Student 19	A-	3.7						
Student 20	A	4.0						
Student 21	B	2.7						
Student 22	A	4.0						
Student 23	B-	2.3						
Average per class		3.25			3.4			4.0

Table 3 Final Grade

Results

The hybrid and online classes were significantly smaller than the face-to-face class. As noted in previous chapters, this is one of the many challenges facing small rural high schools. The difference in the number of students could have impacted the data, but it reflects the actual situation in rural high schools. The data in Chart 14 show that the online class had the highest average grade followed by the hybrid and face-to-face classes.

Summary of the Collected Data

There were numerous things that emerged from the data collection and analysis. One of the main things that emerged from the data was all the different perspectives the data could be viewed from, which item is a cause and which is an affect. These questions reveal how much more in-depth research is needed to sufficiently answer some of the questions.

1. Based on the RAIQ Rubric the Administrators view the face-to-face class as the most engaging/effective.

2. Based on the RAIQ Rubric the students in the hybrid and online classes observed themselves to be much more engaged/effective than all the other observing groups.

3. Based on all the RAIQ rubrics, the Instructional Designer's as a whole appear to be the most critical of engaged/effectiveness of all the classes.

DISCUSSION AND RECOMMENDATION

The literature reviewed stated that the student must be engaged and motivated. Some students are intrinsically motivated while others need to be externally motivated. This motivation can be enhanced by pedagogical application to digital and interactive tools. The student having a sense of belonging in a community is also helpful. This community needs to be facilitated by the instructor. This means the instructor has to be properly motivated and knowledgeable regarding the community of enquiry theory. The VARK Survey (Cherry, 2014) can help both the student and instructor understand how the student learns most efficiently.

The data were collected so the answers between the students in the face-to-face class, the hybrid class and the pure online class could be compared. The data shows that the online and hybrid students were more intrinsically motivated than the students in the face-to-face class.

The collected data does support the literature review. Even though the literature and the collected data support one another there is a gap in existing literature. There is QM and Khan's Framework that defines quality web-based curriculum. There is the community of inquiry theory, VARK (Cherry, 2014) and other individual publications that can contribute to making a quality curriculum effective but there is no single framework that brings all of these concepts together.

CONCLUSION AND FUTURE DIRECTION

The IEDT curriculum has been accepted and used in the state of Utah for three years now. The curriculum has been a success and is being used throughout the state of Utah. The collected data shows that the students are engaged and learning effectively, in all curriculum delivery methods. This provides the rural high school an option to provide online or hybrid concurrent engineering and technology courses to their students with the knowledge that the courses are engaging and effective.

Although the collected data has answered the research questions presented in this paper. The data has also shown additional gaps where future research is required. For example, why did the administrators observe the face-to-face class to be the most engaging but the data shows otherwise? Why are the instructional designers the most critical of curriculum engagement? Why do the students in the class observe themselves to be more engaged than the other groups observed them to be?

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APPENDIX A

RUBRIC FOR ASSESSING INTERACTIVE QUALITIES IN DISTANCE COURSES (© 2004, M. D. ROBLYER)

RUBRIC DIRECTIONS: The rubric shown below has five (5) separate elements that contribute to a course's level of interaction and interactivity. For each of these five elements, circle a description below it that applies best to your course. After reviewing all elements and circling the appropriate level, add up the points to determine the course's level of interactive qualities (e.g., low, moderate, or high).

Low interactive qualities	1 – 9 points
Moderate interactive qualities	10 –17 points
High interactive qualities	18 – 25 points

Note: This is Copy Right 2004, even though this is 11 years old it is still cited and used more than any other rubric. Example, the Online Learning, A Journal of the online learning consortium. (Formerly known as the Journal of Asynchronous Learning). Volume 19, issue 3- June 2015.

As well, Online Learning Insights website: https://onlinelearninginsights.wordpress.com/resources-2/resources-for-developing-online-interaction/ Accessed 9/12/15

The American Journal of Distance Education has re published Roblyer M.D. Desgin and Use of a Rubric to Assess and Encourage Interactive Qualities in distance Courses M.D Roblyer; W.R. Wiencke, Online Publication was 07 June 2010.

V*ariable #1: Social Goals of Interaction:* However, Gilbert and Moore (1998) and Wolcott (1996) note another equally important purpose: establishing rapport and collaboration among class members and between class members and instructor. Thus, interaction can support both social and instructional aims. Gilbert and Moore (1998) agree with this duality of purpose, noting that social rapport and increased collaboration can lead to greater levels of interaction that address instructional goals.

Variable #2: Instructional Goals of Interaction: Our analysis of the distance learning literature indicates that interaction serves two important - but different - functions in learning environments. One purpose is to encourage reflection and discussion on course topics and concepts. Much of the literature in this area focuses on instructional designs to increase this kind of participation and feedback.

Variable #3: Types and Uses of Technologies: Many authors describe the various technologies that can be used to encourage and facilitate interaction. Desktop videoconferencing (Edmonds, 1996, July) and web-based resources (Hughes and Hewson, 1998) currently are among the most popular.

However, equally important to the technologies are the techniques, designs, and methods used to take full advantage of these powerful, evolving resources (Kimeldorf, 1995; Roblyer & Ekhaml, 1999).

Variable #4: Impact of Interactivity-Changes in Learner Behaviors: The last dimension involved in assessing interactive qualities of courses seems the one most often neglected: the impact on learners. McHenry and Bozik (1997) point out that students respond to effectively (or ineffectively) designed distance courses with observable behaviors. This dimension evidences itself most often in an increased or decreased willingness to use the various technology resources (e. g., chat features, microphones), to collaborate with other students, to take responsibility for requesting needed information from the instructor, and to participate in class activities.

Energy and Analytics

A PILOT STUDY INTO UNDERSTANDING THE BARRIERS TO THE UPTAKE OF ENERGY DATA ANALYTICS IN LARGE UK MANUFACTURERS

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Keywords: Energy Data Analytics, Energy Efficiency, Energy Information Systems, Grounded Theory.

ABSTRACT

The need for the reduction of energy use within industry is increasingly important. In response to this, the focus on energy management has grown alongside the development of more efficient technologies and practices. This has, more recently, coincided with the growth in Big Data platforms and the use of data to aid with the evaluation, development and synthesis of ideas within both commercial and industrial sectors. This conjunction of developments has given rise to a new field called Energy Data Analytics. This is a tool that will aid energy managers and consultants to visualize the unseen, identify the unknown and validate complex interventions. The problem is that the uptake and use of this tool is seemingly low, especially within industrial energy users, with few case studies or examples in the public domain. However those that do exist are predominantly positive. This study seeks to identify and characterise the barriers which are preventing manufacturing organisations from using energy data analytics to bolster or underpin a program of energy reduction.

This paper presents a pilot study in understanding the barriers to the uptake of energy data analytics with specific reference to large manufacturers based in the UK. The study findings will provide an overview of the current literature, from both an energy efficiency and information systems perspective. It will also discuss the approach taken to assessing this subject, along with an overview of the initial findings from a selection of expert interviews. These are compared with a newly developed framework with the overall aim of refining the research process, in order to allow the main research phase to proceed with confidence.

INTRODUCTION

With the increasing need to reduce energy use for environmental, economic and social reasons, manufacturers, including those within the UK, are expected to play a significant role by decreasing the energy intensity of their operations (Dunn, 2002, Boiral, 2006, Abdelaziz *et al.*, 2011, Trianni *et al.*, 2014). In response to this the energy management sector has grown as a whole and accelerated the advancement of systematic energy management systems and approaches (Cummins, 2011, Claeys-Jackson, 2015). Numerous improvements in energy efficiency can be seen in products and plant, and in the addition of data enabled platforms and services. One new area is the advent of energy data analytics (EDA). This concept arises from the need to reduce energy use, in conjunction with increases in data availability and software capability. In the past it has predominantly been used in the large scale energy sector (Williams, 2014), but the concept is now being used in industrial circles. From initial evidence this seems to have been successful. However the uptake of this energy concept seems to be slow within the manufacturing sector despite its ability to aid with reducing energy use. The overarching aim of this research is to establish what the barriers to the uptake of energy data analytics are specifically, within large UK manufacturers. This pilot study was undertaken with the intention of demonstrating and testing the research methodology to be used in the main part of the study, along with associated tools, and techniques.

Energy Data Analytics Concept

The standardised approach to conventional energy auditing has been the subject of considerable research and is an accepted methodology for reducing energy use (Schleich, 2004, Rosenqvist *et al.*, 2012) a position supported and shared by Oung (2014). The fundamental idea of energy data analytics as a means of identifying energy inefficiency, is discussed to various levels and detail by the authors mentioned above. Energy data analytics is essentially the extrapolation and modelling of data relating to a building, plant or process to identify baselines, energy performance indicators and, most importantly, inefficiencies. The building blocks of EDA are based in the fundamentals referred to above specifically concerning energy auditing, energy monitoring and data analysis (Bunse *et al.*, 2011, Zampou *et al.*, 2014). However its rapid incorporation into the toolbox of energy managers and the energy management services marketplace may be attributed to the somewhat meteoric rise of big data and data analytics itself. A visual representation of energy data analytics is shown in Figure 1. This figure shows how energy data analytics could be viewed and how possible barriers are linked to the concept.

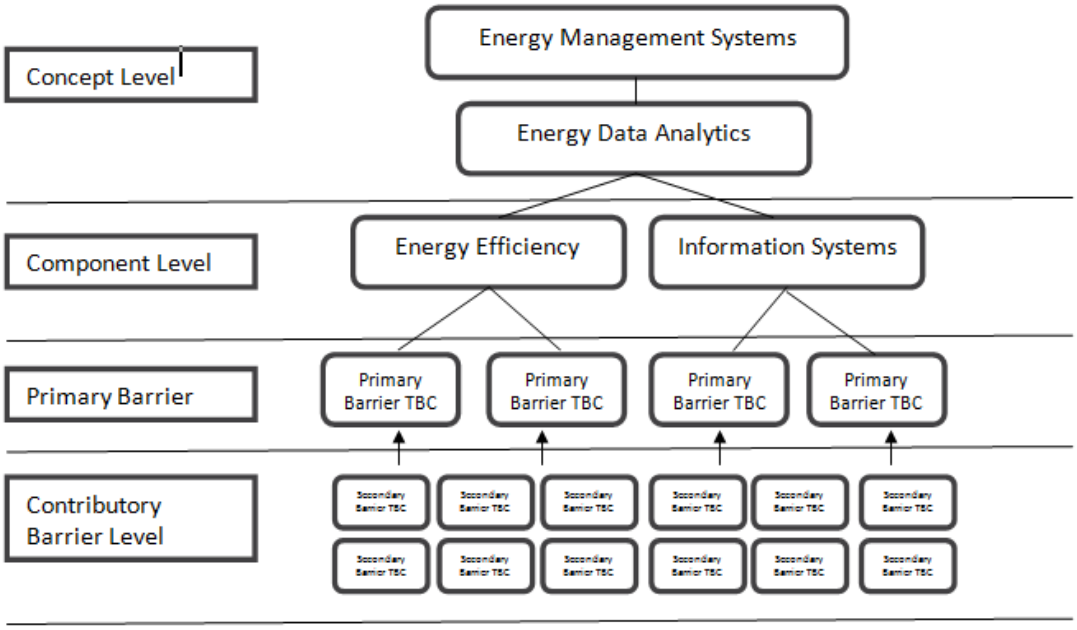

Figure 1. Conceptual diagram of EDA and associated barriers to uptake

The EDA proposition was first explored in the energy generation marketplace, where the high level of available data associated with energy generation allows for a detailed analysis (Williams, 2014). This was closely followed by its use in commercial buildings, specifically in relation to building management systems (Vrbsky *et al.*, 2013, Hong *et al.*, 2014). With the advent of big data and the associated software developed by large companies such as General Electric's energy services division (2013), the extension of energy data analytics to become a tool for buildings and industrial energy efficiency applications seems logical. It is clear that the application of energy data analytics, as part of an energy management audit or programme, is becoming more common as people accept the advantages that big data and the analysis of the data can provide (Sahay *et al.*, 2014).

Barriers to the uptake of energy data analytics

A literature review was undertaken to establish the background on energy data analytics and related fields. Key areas of exploration centred on existing work in the fields of energy efficiency barriers and information systems barriers. Extensive work on the classification of barriers relating to energy efficiency has been undertaken by numerous researchers. More recent research into energy efficiency barriers (Thollander *et al.*, 2010, Trianni & Cagno, 2012, Cagno *et al.*, 2013, Sudhakara Reddy, 2013, Cagno & Trianni, 2014) has followed the previous work of Sorrel *et al.* (2000). A comprehensive review of existing research into barriers to the adoption of energy conservation measures within industrial energy users was undertaken by Brunke *et al.* (2014). A review of this research shows the three main energy efficiency barriers to be:

- Access to Capital (or similar economic considerations)
- Power
- Hidden Costs

Research on barriers regarding energy information system and/or energy data analytics was found to be much less abundant with some commentary attributing this to the newer positioning of the proposition within the energy management market place. Schwister & Fiedler (2015) offer an analysis

and filtration exercise on information system barriers as part of wider research on energy information system barriers, and attribute these barriers to three broad categories:

- Adoptions costs
- Switching costs
- Collective action dilemma.

The literature review process revealed a lack of specific research in the area of energy data analytics despite its potential importance to the energy management industry. By understanding the barriers to the uptake of EDA we may be in a better position to mitigate these.

RESEARCH METHODOLOGY

Grounded Theory

Where there is little existing theory on a subject matter, Grounded Theory Methodology (GTM) has been widely used (Fendt & Sachs, 2008). This is based on the principle of using data to discover theory / knowledge rather than to verify hypotheses. Its use is widely seen in the natural and social science fields including works of a similar background to this study. A considerable limitation of GTM is the differing methodological approaches available that have evolved since its conception in the 1960s. Often described as a family of methods, this GTM openness can lead to misunderstanding of approach philosophy or the 'muddling' of approaches during a research process. Consequently this may lead to the reader failing to understand the parameters of the approach taken (Evans, 2013).

For the purposes of this research the Straussian method was adopted due to its use in similar works. The methodology also outlines a structured and traceable approach to data analysis. However there is opportunity to modify and evolve the methodology to enable hurdles to be overcome. Hood (2006) suggests that the three main features of GTM that distinguish it from any other research methods are theoretical sampling, constant comparison of data to theoretical categories and theory development via theoretical saturation. This is a supposition supported and quoted by Bryant and Charmaz (2010). These GTM generating features have been used as the key principles of the pilot study methodological approach, where possible.

Theoretical Sampling

Theoretical sampling is the process of data collection where the intention is to generate theory as it emerges from the data analyses process (Glaser & Strauss, 1967); with the process being derived directly from memos taken by the researcher. Our approach to generating memos focused on the use of semi-structured interviews with industry energy experts. As this was a pilot study, only four interviews were undertaken at this stage. To ensure consistency between interviews, an interview guide was developed and vetted by peers. All interviews were conducted over the telephone and lasted, on average, forty minutes. All interviews were personally conducted and recorded by the lead author. The interview questions focused on obtaining the participant's opinion on what energy data analytics is and what barriers prevent its uptake, in relation to UK manufacturing.

A non-probability sampling technique with a snowball methodology was employed for participant selection. This decision was based on the viewpoint that the field of energy data analytics used in industry is relatively new and therefore understanding is likely to be limited outside the wider energy

services, information systems and manufacturing sectors. For this reason a purposive approach to identifying participants was required. These were drawn from a personal network of contacts including a significant number of field experts who may be representative of the wider population. The participants included:

#	Role	Sector
1.	Senior Energy Consultant	Large multi-disciplinary consultancy
2.	Site Energy Manager	Industry – Metals / Manufacturer of engineered parts
3.	Group Energy Manager	Industry – Minerals / Aggregates / Cement
4.	Group Carbon Manager	Industry – Minerals / Aggregates / Manufacturer of mineral products

Table 1, Interviewee roles

Constant Comparison

Constant comparison is a way of maintaining close connection between codes, categories and the data (Gibbs, 2010) to ensure theoretical elaboration. Coding is undertaken to achieve this and is based upon the transcribed interviews and associated memos taken by the researcher for analysis purposes. However within this pilot study, its use is limited as the number of interviews is low at this stage.

The coding process provides key comments, words and themes that form the basis of a list of barriers and possible motivations. This was undertaken utilising a 3-stage systematic process, as defined by Strauss and Corbin (1990).

- Open Coding - is the part of the analysis concerned with identifying, naming, categorizing and describing phenomena found in the transcribed text.
- Axial Coding - is the process of exploring the relationship between codes / categories, through a combination of inductive and deductive thinking. Causal relationships are identified between the data allowing the establishment of generic relationships.
- Selective Coding - is the process of choosing one category to be the core category, and relating all other categories to that category. This generally relates to the derived phenomena from the axial coding stage.

Theoretical Saturation

Rowlands *et al*. (2015) suggest that theoretical saturation is fundamentally a measure of sufficient sampling usually associated with interview based research. For the purposes of this pilot study, theoretical saturation was not achieved.

Framework Selection

To ensure that a boundary to the research is established, a research framework is required. Energy data analytics is a concept that sits in both energy efficiency and information system fields (See Fig. 1). A framework to compare researched barriers was required to reflect this. A published taxonomy on energy efficiency barriers developed by Thollander *et al.* (2010) was therefore combined (See Table 2) with a published taxonomy on energy information systems by Schwister & Fiedler (2015).

Category	Framework 1 Theoretical Barrier	Framework 2 Theoretical Barrier		Combined Theoretical Barrier
The Technical System	Access to capital	Financial costs	→	Access to capital
	Heterogeneity	----	→	Heterogeneity
	Hidden costs	Switching costs	→	Hidden Costs
	Risk	----	→	Risk
The Technological Regime	Imperfect information	----	→	Imperfect information
	Adverse selection	----	→	Adverse selection
	Split incentives	----	→	Split incentives
	Form of information	----	→	Form of Information
	----	Managerial complexity due to lack of interoperability	→	Managerial complexity due to lack of interoperability
	----	Transaction risks	→	Transaction risks
The Socio-Technological Regime	Credibility and Trust	----	→	Credibility and Trust
	Principal-Agent relationships	----	→	Principal-Agent relationships
	Values	----	→	Values
	Inertia	----	→	Inertia
	Bounded rationality	----	→	Bounded rationality
	Power	Standard development dilemma / Standard diffusion dilemma	→	Power
	Culture	----	→	Culture
	----	Legal barriers	→	Legal barriers

Table 2, Combined barrier framework

RESULTS AND DISCUSSION

Through the coding process seven main categories were established which were compared and allocated, if relevant, to known barrier theories as found during the literature review process and outlined framework. This transition is outlined in the table below:

Identified Category	Theoretical Barrier	Findings Summary
Third Party Support	Credibility and Trust	Lack of credible/trustworthy support from third parties; specifically suppliers and government.
Applicability	Heterogeneity	Differing sectors and/or processes hamper the applicability or effective use of EDA.
Data Related Issues	Form of Information	Issues relating to data availability, granularity and format.
Knowledge of EDA	Imperfect Information	Lack of EDA understanding and systematic approach. Lack of available skill sets within organisations noted.
Access to Funding / Capital	Access to Capital	Return of investment, access to funds and general payback all referenced.
Top Level Commitment	Power	Specific reference to lack of leadership / commitment to invest in EDA. Large number of mentions regarding adoption of a systematic approach.
Technical Barriers	Managerial complexity due to lack of interoperability	Specifically relating to both hardware and software issues.

Table 3, Transition of categories to theoretical barriers

By analysing the distribution of mentions across the identified barriers we can form a first impression as to which barriers were the most discussed during the interviews (Figure 2). From the graph it is clear that references to Power featured the most prominently with Managerial Complexity due to Interoperability and Credibility and Trust, ranking second and third.

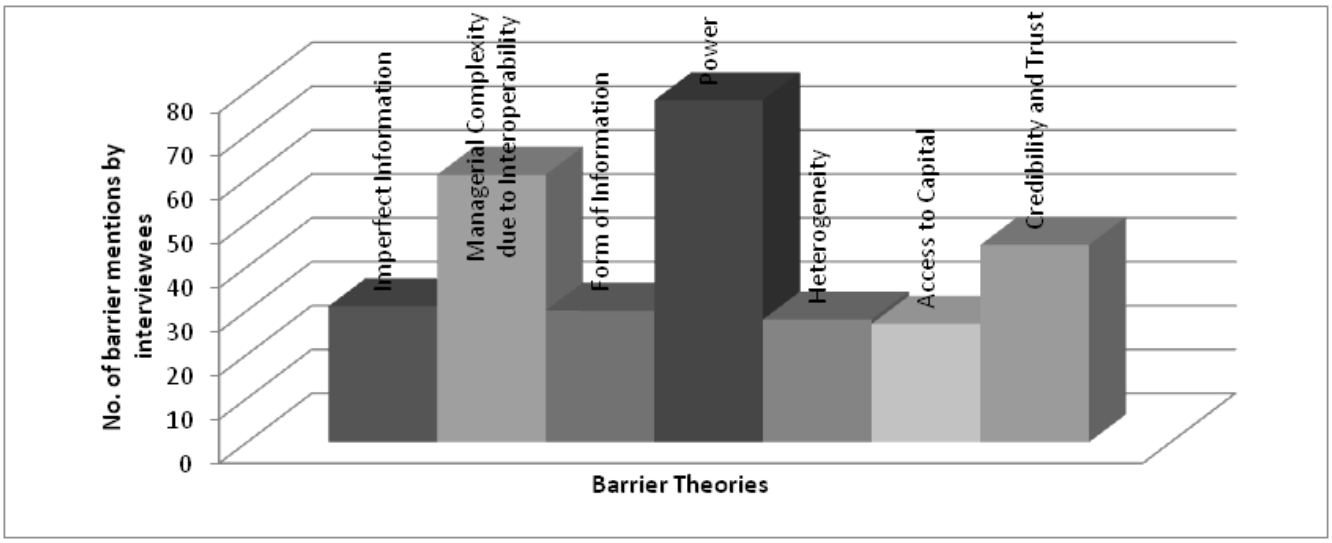

Figure 2. The distribution of barriers to EDA in UK industry

This preliminary research indicated that there are (at least) seven primary barriers to the uptake of energy data analytics for UK manufacturers. Of these seven, three barriers were most prominent. These three are discussed in more detail below.

Power

The barrier classified as 'power' relates to the low status of energy management and associated facets such as energy data analytics, leading to a lower priority to implement energy management as a whole in organisations. The coded information relating to this barrier was abundant and broke into two main sub-sections.

Prioritisation

Responses circled around the prioritisation of issues relating to other business related activities with 'production' featuring heavily. However it was found that there were other barriers, including Hidden Costs and Values. With regards to the costs associated with additional resource to design, manage and maintain an EDA package along with the associated costs for software upgrades and licences. With regards to Values; the research suggested there is a lack of ambition or enthusiasm for energy management and / or EDA. With further research it may be the case that these are barriers in their own rights, however equally possible is that these barriers, individually, maybe the possible stimulus for a lack of commitment from organisation leaders, which in turn has led to the barrier labelled Power.

Systematic Approach

All interviewees commented on the broad subject of energy management systems, ISO5001 and standardisation, which was conceptualised under the universal term systematic approach. However it was viewed that if the lack of use of EDA may be directly related to the lack of a systematic approach; then the lack of a defined system is directly related to the lack of prioritisation from organisation leaders. This supposition is inconclusive; further research is required.

Managerial Complexity Due to a Lack of Interoperability

This barrier relates to the absence of universally accepted standards including interfaces, messaging and protocols, which are necessary to ensure common communication. What was evident from the research processes was that there were common issues surrounding the technical issues regarding hardware and software required for successful EDAs. The specific barrier identified may not be written, visual or verbal communication but may actually be the inability of different information technologies to communicate with each other due to poor set-up, differing system protocols or incompatibility. As this seems to be a separate area within the listed combined framework barrier, it may be the case that this is a barrier in its own right. It is also likely that it overlaps with other barriers identified such as '*imperfect information*.' Whilst it was not one of the three most prominent barriers identified it was significant. However one of the axial codes was a specific lack of EDA resources and EDA skill set availability. Both of these could be viewed as essential to defining appropriate hardware and software capability to engender effective communication (Information technology related). Therefore this may actually be a pre-barrier or an underlying facet to '*managerial complexity'* identified above.

Credibility and Trust

This barrier relates to the necessity for credibility and trustworthiness of the information source in order to successfully deliver information regarding energy data analytics. If these factors are lacking, it may result in inefficient choices being made. This is thought to be relevant on both an internal and external basis:

- External – Information provided from a third party to an organisations representative(s).
- Internal – Information from one colleague to another i.e. generation of a business case by an energy manager for managing director.

The coded information focussed more on external support-based issues which, in turn, could be broken into two sub-sections:

Supplier Support

Organisations require more support from third party suppliers to aid them in their EDA journey. However there is a fundamental lack of trust in the goods and services that third party suppliers are either selling or delivering. This mistrust revolves around software capability itself, over-selling software capability and the lack of availability to support issues cost-effectively.

Formal Approach

There is a lack of support, in the form of communication, from formal institutions such as government, academia and professional bodies about EDA. It was mentioned that communication activities in the sphere of EDA was poor with no direction, examples or discussion taking place.

Remaining Identified Barriers

Four additional barriers were identified during the research process which shared almost equal representation within the coding process. These include:

- Imperfect Information
- Form of Information
- Access to Capital
- Heterogeneity

It is viewed that all four are important, but they may actually be the result of an initial primary barrier or a combination of other barriers. Further work will be necessary to establish whether or not this is the case.

CONCLUSIONS

From this pilot study it is clear that the barriers to the uptake of energy data analytics share commonality with previous research in the broader areas of energy efficiency and information systems. It is also suggested by the research data that the most common barriers seen may differ from those seen in previous research in these broader areas. This may be due to the newer nature of the concept or the lack of a recognised formal system to reference from. It is evident that with EDA existing barrier theory may require evolution and / or modification, especially when concerning more technical matters such as technological communication. However, existing theory in energy efficiency and information system barrier mitigation / drivers for change may be viable for some barriers found such as 'Power.'

The continuation of this research into the main phase will go some way to clarifying which barriers are the most prominent in hampering the uptake of EDA in UK manufacturing and why this is the case. The aims of this pilot study were first and foremost to test the methodological approach. Confidence is high that the approach is appropriate for the main study. However, confidence in the level of accuracy of the findings is limited, as only four interviews were carried out.

Further Areas of Study

The research methodology utilised in this pilot study is appropriate for further examination of the barriers to the uptake of energy data analytics. The following are suggested ways in which new avenues and theories might emerge, by adjusting key variables within the research methodology.

- *Scale* – Maintain the current approach but increase the sale of the research by interviewing qualified participants until theoretical data saturation is achieved.
- *Interviewee Classification* – Focus on a singular classification of interview participant i.e. energy manager or energy consultant.
- *Location* –Alter the geographical location from the United Kingdom to another country. Alternatively utilise the research methodology to assess any differences between smaller sub-regions within the United Kingdom.
- *Sub-Sector Approach* – Focus on one specific industrial sub-sector to assess where energy data may have the most impact e.g. brewing
- *Definition* – Look to research barriers associated with the apparent lack of definition of energy data analytics. Although not significantly mentioned in this pilot study, the outcomes of the pilot study did indicate a lack of uniformity in all four interviewee answers regarding definition. This may feature as a barrier in its own right.
- *Output for Change* – Look to use the research findings to help define an output for change; that will support the use of energy data analytics in reducing industrial, if not wider sector, energy use.

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PCA BASED NEURAL NETWORK MODEL FOR IDENTIFICATION OF LOSS OF COOLANT ACCIDENTS IN NUCLEAR POWER PLANTS

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Keywords: Principal component analysis, nuclear power plant, safety, neural networks, diagnosis.

ABSTRACT

Nuclear power plants (NPPs) are extremely complex systems that are operated and monitored by human operators. Maximum care is exercised to keep the likelihood of potential risks to a very low value. However, in the event of an unlikely abnormal occurrence, the operator has to take necessary actions relatively fast, which involves complex judgments, making trade-offs between partly incompatible demands and requires expertise to take proper decision. Over the years, several intelligent systems have evolved to assist the operator for decision-making; however they are highly computationally intensive and may not be suitable for real-time online monitoring or may require large amounts of data. In this paper, an efficient neural network (ANN) model has been developed based on principal component analysis (PCA) for identification of large break loss of coolant accident (LOCA) in NPPs. A large database of reactor process parameters is generated through various thermal hydraulic codes and PCA was performed for 32 break scenarios of LOCA in inlet and outlet reactor headers with and without the availability of emergency core cooling system (ECCS). The PCA was used to optimize the inputs of ANNs. The results of comparison between the classical and PCA-based ANN has been presented in this paper. The simplified ANN model based on PCA is relatively in good agreement with the classical ANN model. It can be said that the PCA based ANN gives a great computational advantage, due to an important factor when the input parameters dimension is substantially optimised and is usually a case in NPPs. However, there is a scope of improvement in the PCA based ANN in terms of reduction of error, and this could be achieved by incorporating more of variance during dimension reduction by PCA and also applying different architectures of ANN.

INTRODUCTION

Safety is an important aspect to be considered in a nuclear reactor. Maximum care is exercised to keep the likelihood of potential risks to a very low value. However, in the event of such an unlikely occurrence, the operator has to take necessary actions relatively fast, which involves complex judgements, making trade-offs between partly incompatible demands and requires an expert's opinion. Timely and correct decisions in these situations could either prevent an incident from developing into a severe accident or to mitigate the undesired consequences of an accident. The objective of this study is to develop a system, which assists the operator in identifying an accident quickly using ANNs that diagnose the accidents based on reactor process parameters, and continuously displays the status of the nuclear reactor. A large database of transient data of reactor process parameters has been generated for reactor core, containment, environmental dispersion and radiological dose to train the ANNs. These data have been generated using various codes e.g., RELAP5 - thermal hydraulics code for the core. The present version of this system is capable of identifying large break LOCA scenarios of 220 MWe Indian pressurized heavy water reactors (PHWRs). The system has been designed to provide the necessary information to the operator to handle emergency situations when the reactor is operating. The diagnostic results obtained from ANNs study are satisfactory. The previous work has been able to identify smaller breaks of inlet headers and location well based on NNs, but have had problems to identify large breaks (Santosh et al 2002). This is one of the major obstacles for a successful tool. Because the large break transients are so rapid and many process parameters change almost simultaneously (Santosh et al 2013, Coble et al 2012, Famtoni and Mazzola 1996, Kim and Bartlett 2006, Renders et al 1995, Santosh et al 2002). This study attempted to get a better performance and was extended to apply the PCA to optimize the inputs of ANNs. The results of comparison between the classical and PCA-based ANN has been presented in this paper. The simplified ANN model based on PCA is in relatively good agreement with the classical ANN model.

The Indian PHWR

The primary heat transport system (PHT) of 220 MWe Indian PHWRs is shown in Figure 1 (Santhosh et al, 2014). There are 306 horizontal coolant channels in 220 MWe Indian PHWRs. Each channel consists of 12 fuel bundles contained in a pressure tube, which is surrounded by a calandria tube. The calandria tube is submerged in the relatively cold heavy water moderator. The primary coolant flows inside the pressure tube containing the 19-rod fuel bundle.

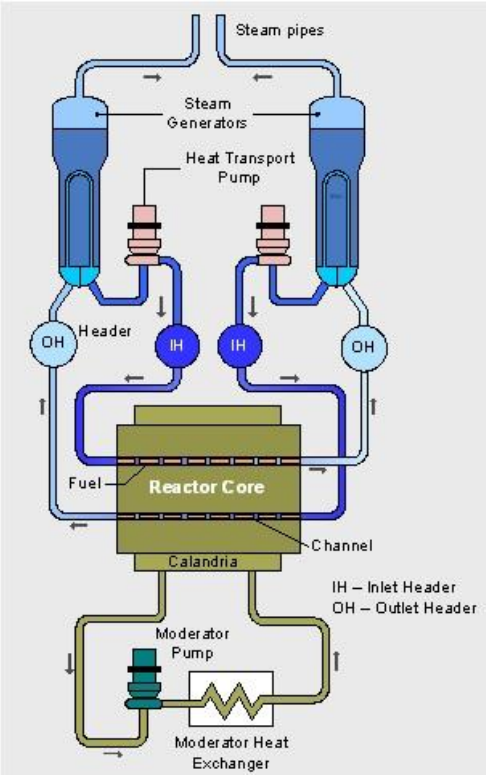

Fig. 1: PHT system of Indian PHWR

Auxiliary systems, like feed and bleed systems, help to maintain the system inventory and the pressure and is achieved with the help of a PHT storage tank, bleed condenser and pressurizing pump. The reactor is equipped with ECCS with heavy water and light water hydro accumulators along with a long term pumped recirculation system. Indian PHWR has two shutdown systems namely, primary shutdown system and secondary shutdown system to bring the reactor to a shutdown state. ECCS is designed to limit the consequences of events such as LOCA.

All the instrumentation and control parameters are continuously displayed on a computerized operator information system (COIS), which is located in the main reactor control room. These process parameters can be utilized to identify the plant state using computational intelligence methods.

Transient Analysis and ANN Modeling

To study the system behavior under large break LOCA condition a wide range of break sizes is considered. A spectrum of break sizes have been analysed for the core and containment. Following are some of the typical process parameters' profiles obtained from RELAP5 simulation for a 200% break in RIH with the availability of ECCS. For example, Figure 2 shows the header pressure in the broken and unbroken pass and Figure 3 shows the D_2O inventory in the PHT system (Santosh et al 2009).

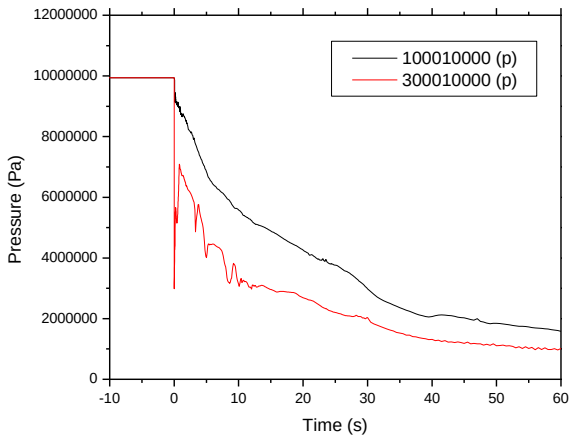

Fig. 2: RIH pressure (Pa)

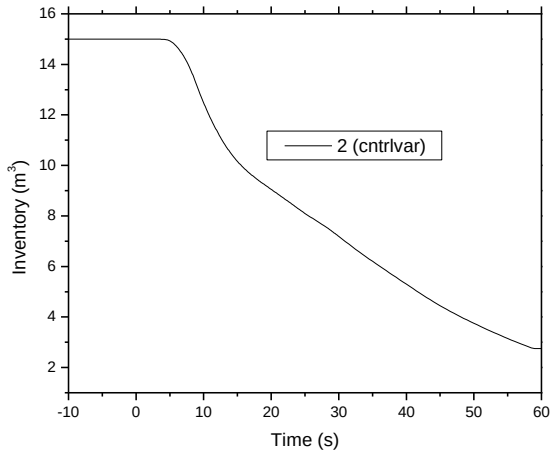

Fig. 3: D2O inventory in PHT system (m3)

The events are modelled based on the relevant reactor process parameters' time dependent data as available in the COIS. A large amount of time dependent data has been generated in order to train and test the neural networks for the selected scenarios so that these scenarios can be identified during reactor operations (COIS, Santosh et al 2007).

The input parameter list consists of 35 analog and 2 digital parameters derived from two analog parameters such as containment pressure and high log rate. The analog parameters will have a time dependent transient data whereas the digital parameters indicate the status of certain process states such as reactor trip and pump room pressure high. This type of problem is modelled as a pattern recognition problem in the artificial neural networks wherein a set of input values (known as pattern) with respect to time represents a class of output. Thus, the events are classified into several classes based on the input patterns. In order to illustrate the developed methodology, large break LOCA in RIH with ECCS is selected. The break sizes considered for this event are 20%, 60%, 75%, 100%, 120%, 160% and 200% of double ended break in RIH. In addition to these break cases, the normal operating condition of the reactor is simulated. A 60 second transient duration is considered in this case under the assumption that this time duration is sufficient to identify the large break LOCA.

To accomplish this task, a neural network consisting of 37 input neurons and 3 output neurons has been selected. A 3-neuron output pattern represents as follows: the first parameter of the output represents the size of the break (percent of cross-sectional area), the second parameter representing the location of the break (i.e., 0 for RIH and 1 for ROH) and the last parameter representing the status of ECCS (i.e., 0 for without the availability of ECCS and 1 for with the availability of ECCS). Table 1

shows the representation of output neurons for a 20% break case. A similar representation was followed for other break scenarios.

Table 1: Output representation

Output pattern	Description
20.0, 0.0, 0.0	20% break in RIH with ECCS
20.0, 0.0, 1.0	20% break in RIH without ECCS
20.0, 1.0, 0.0	20% break in ROH with ECCS
20.0, 1.0, 1.0	20% break in ROH without ECCS

The number of hidden layers and neurons in each layer were selected based on the study presented in (Santosh *et al* 2014). The first order resilient back propagation algorithm with batch mode of training was employed. Unipolar sigmoid activation function and sum squared error function were used. Training of ANN was carried out on a typical Pentium IV processor with 1.5GHz and 512MB of RAM. The total CPU time the simulator took was approximately 24Hrs to converge to a minimum error of 1.42E-02 in about 76000 epochs. A few case studies were carried out with the transients of some selected event scenarios which were not used for training and testing of the ANN. Figure 4 shows the plot of desired verses calculated breaks and Figure 5 shows the predicted breaks verses the RMS error in percent.

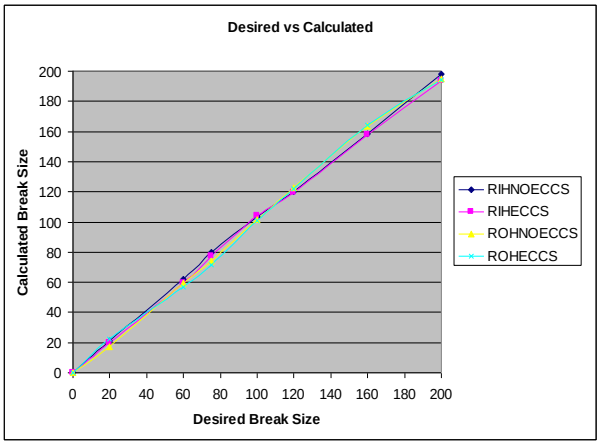

Fig. 4: Desired vs. calculated output of ANN

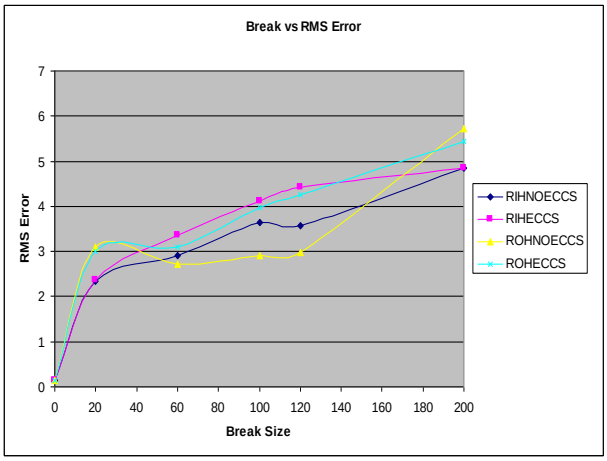

Fig. 5: Predicted breaks vs. RMS error (%)

It can be seen from Figure 4 that the predicted breaks are in good agreement. From Figure 5, it is clear that the RMS error for smaller breaks is less compared to larger breaks. This is because of the fact that the large break transients are so rapid that many process parameters come almost simultaneously and ANN may not distinguish accurately due to lack of uniqueness in the patterns.

Principal Component Analysis

A common problem in statistical pattern recognition is that of feature selection or feature extraction. *Feature selection* refers to a process whereby a *data space* is transformed into a *feature space* that, in theory, has exactly the same dimension as the original data space. However, the transformation is designed in such a way that the data set may be represented by a reduced number of "effective" features and yet retain most of the intrinsic information content of the data; in other words, the data set undergoes a *dimensionality reduction.* To be specific, suppose we have an m-dimensional vector x and wish to transmit it using *l* numbers, where $l < m$. If we simply truncate the vector x, it will cause a mean-square error equal to the sum of the variances of the elements eliminated from x. Clearly, the transformation T should have the property that some of its components have low variance. Principal components analysis maximizes the rate of decrease of variance and is therefore the right choice.

PCA based ANN

The input data for identification of LOCA scenarios has 37 parameters. This requires a substantially high amount of computation during the ANN processing. To reduce this data set, PCA was applied on 37 parameters and thus giving 19 principal components which accounted for 99% variation in the input data. The scree plot of the PCA is shown in Figure 6.

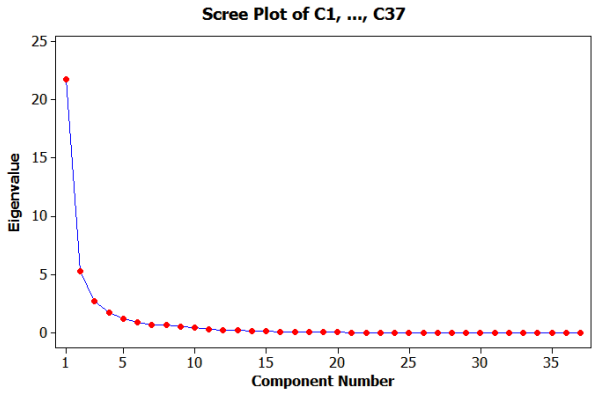

Fig. 6: Scree plot of PCA

The architecture used for transient prediction is the feed-forward artificial neural network with resilient back-propagation learning algorithm. The learning rate was kept 0.7 and the momentum factor was kept 0.5. Initial weights were kept random between -0.5 to +0.5. The input layer consisted of 19 neurons. Initially the data consisted of 37 parameters of input having 6223 observations. Using principal component analysis, the dimension of the data was reduced to 19 parameters. Hence, the input layer now consisted of 19 neurons. The hidden layer and output layers had 10 and 3 neurons respectively. 100,000 iterations were run on the data to train the network. The predictions of ANN with and without PCA are shown in Figure 7 for break in inlet header without the availability of ECCS.

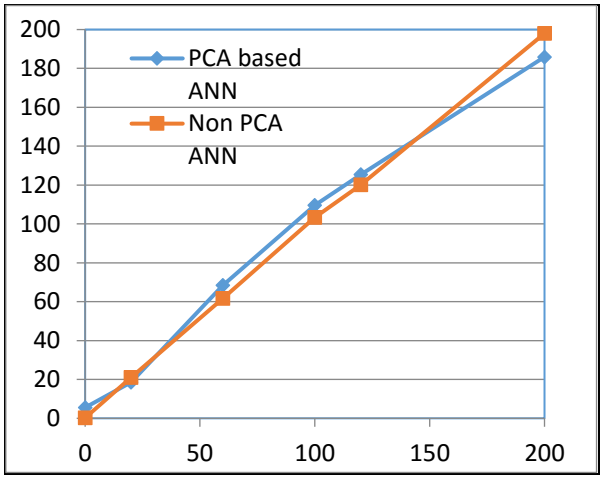

Fig. 7: ANN predictions

Diagnostic system

Diagnostic system is an artificial intelligence based operator support system for accident management in 220 MWe Indian PHWRs. It has been developed to monitor the status of the nuclear reactor based on various process parameters, to detect deviations from normal operating conditions, and to determine the significance of situation and recommend an appropriate response in a short time. It performs the above-mentioned tasks by operating on a large knowledge base which was generated from RELAP and other popular simulation codes. Currently, Diagnostic system can harness the advantage presented by the efficient logging of important plant parameters in various computer based systems such as computerized operator information system (COIS), radiation data acquisition system (RADAS), etc. Diagnostic system has been set up with a high speed distributed computing servers for fast processing and real-time response and has been demonstrated successfully for real-

time identification of accident scenarios in NPPs. The set up of Diagnostic system commissioned at BARC by RSD is shown in Figure 8. The system has the self diagnostics which monitors the internal servers and various remote tasks to ensure the round-the-clock operation for real-time diagnosis of transients in NPPs. The transient prediction and plume dispersion by Diagnostic system are shown in Figure 9 and 10 respectively.

Fig. 8: Diagnostic system at BARC

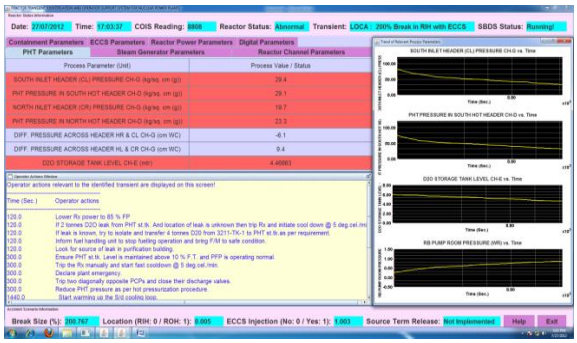

Fig. 9: 200% LOCA prediction in RIH with ECCS

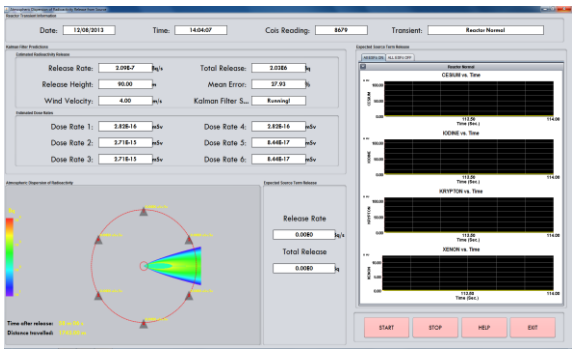

Fig. 10: Radioactivity plume dispersion

CONCLUSIONS

In this paper, the results of an efficient neural network model based on PCA for transient identification has been presented. The prediction obtained from the simplified ANN model based on PCA is in relatively good agreement with the classical ANN model for a typical LOCA scenario. It can be said that the PCA based ANN gives a great computational advantage, due to an important factor when the input parameters dimension is substantially optimized and is usually a case in NPPs. However, there is a scope of improvement in the PCA based ANN in terms of reduction of error, and this could be achieved by incorporating more of variance during dimension reduction by PCA and also applying different architectures of ANN.

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DESKTOP INVESTIGATION TO EXAMINE THE RELATIONSHIP BETWEEN INDOOR ENVIRONMENTAL CONDITIONS AND PRODUCTIVITY IN WORK SPACES

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Keywords: IEQ, office productivity, control.

ABSTRACT

Indoor environmental conditions, such as air quality and temperature, can have an impact on productivity. However, quantifying the relationship between indoor environmental quality (IEQ) and productivity is challenging, and current building controls typically fail to optimise the environment for building users. This paper reviews current approaches and metrics for measuring IEQ and productivity in workspaces, and then examines the relationship between IEQ and productivity through a review of literature and a meta-study. The desktop research shows sixteen studies across the world which have demonstrated the influence of the indoor environment on productivity through controlled experiments in climate chambers and real office environments. Furthermore through information collected through Building User Survey (BUS) questionnaires, the relationships between self-reported productivity, perceived environment and control are assessed as a meta-study. BUS questionnaires were administered in 21 low energy offices which were part of Innovate UK's national Building Performance Evaluation programme. Across the 21 buildings, BUS survey results showed that perceived productivity increased by an average of 5% and a maximum of 10%. Overall comfort accounted for 72% (r^2=0.72) of the variation in perceived productivity while satisfaction with noise levels was found to have a weak correlation with perceived productivity, explaining only 3% (r^2=0.03) of the variation in productivity. Insights from the analysis can help in improving (perceived) control of indoor environments as a means for improving productivity in workspaces.

INTRODUCTION

Poor health outcomes and sickness cost UK employers more than £9 billion a year through absenteeism alone (ONS, 2014), while presenteeism costs associated with low productivity could be even greater. Some poor health outcomes have been associated with spending prolonged periods of time in office environments, with ill effects including musculoskeletal complications (Coggon et al., 2013), cardiovascular disease (Smith et al., 2016), and sick building syndrome (Shahzad, Brennan, Theodossopoulos, Hughes, & Calautit, 2016). Improvements to office environments should therefore be able to positively impact the health, wellbeing and productivity of employees, while at the same time reducing the cost to employers.

Indoor environmental quality (IEQ) parameters in office buildings have been found to influence workers productivity (Alker et al. 2015 and references therein). However, optimising conditions to facilitate a more productive workplace is challenging, and as yet there are no clearly defined parameters to guide the optimisation of conditions in a range of office environments. The majority of the intervention and office-based studies that have shown increased productivity from improved IEQ have focussed on individual IEQ elements, e.g. temperature or ventilation rates (Niemelä, Hannula, Rautio, Reijula, & Railio, 2002; Park & Yoon, 2011; Seppänen, Fisk, & Lei, 2006). This is however not representative of a real office setting which experiences dynamic conditions where variables such as temperature, relative humidity (RH), ventilation rates, and air pollutants vary across the course of the day. When interpreting data collected in office environments further challenges exist, such as isolating effects of temperature from air quality; daylighting from outside views; and background noise that can benefit productivity versus distraction which impacts on workflow and concentration. In addition, office design, layout and biophilia have all been shown to influence productivity and interact with IEQ variables controlled by building services.

This paper reviews current approaches and metrics to classify productivity and to examine the relationship between productivity and perceived environment and control related to offices. Building User Survey (BUS) questionnaires collected from 21 low energy offices have been analysed to investigate productivity improvements relating to perceived environment.

METHODS

For existing evidence on the effect of IEQ and productivity, computerised searches and reviews of peer reviewed journal articles and conference proceedings was conducted to identify recent, relevant studies investigating the link between IEQ parameters and indicators of performance relevant in office type work. The included studies vary in location of study, the sample size, study method, IEQ parameters investigated and productivity metrics used. The study methods have been (1) intervention studies in laboratories simulating office environments or actual office environments where selected environmental parameters are created and controlled or (2) observations in actual office environments (without interventions). (Table 1 presents a summary of studies reviewed.)

To examine the relationship between productivity and perceived environment, occupant survey data was obtained from the building performance evaluation (BPE) studies conducted in selected low energy office buildings and buildings with office spaces, all of which are located in the UK. The BUS questionnaire was adopted for the BPE programme. It is a structured questionnaire covering 45 key variables related to the environment, personal control of the environment, the overall building and

the workspace. Occupants rate their satisfaction with the variables on a seven-point scale ranging from 1 for unsatisfactory/uncomfortable/no control to 7 for satisfactory/comfortable/full control. Occupants are also asked to rate their perceived productivity due to the environmental conditions in the building on a nine-point scale ranging from 1, representing -40% of less decrease in productivity to 9, representing +40% or more increase in productivity. Occupants' ratings are given a score and rated against the BUS international benchmark. The analysis presented is based on responses from 1,309 occupants from the 21 buildings. To assess the relationship between the environmental and building related variables and perceived productivity, a regression analysis was conducted, with perceived productivity as the dependent variable (outcome) and the environmental and building variables as the independent variables (predictors). The proportion of the variation (r^2) in the outcome that is explained by the predictors was calculated in order to provide a gauge for the size of the effect. The relationships are based on the self-assessments metrics (both predictors and outcome).

METRICS FOR MEASURING PRODUCTIVITY

Productivity is characterised by quantitative and qualitative output during periods of active work. Several research approaches have been used to measure productivity. Self-assessment of productivity, total time from initiation to completion of discrete tasks, number of tasks completed and accuracy of task results have been used in both intervention studies and field observation studies. In most intervention studies conducted in laboratories, measureable neurobehavioural tests typical of office work such as calculations, proof-reading, text-typing and execution functions are often used as metrics for productivity. Performance in these tasks is measured in time taken, total number of units completed and accuracy of results. In observational field studies, questionnaires are often used for self-assessment of productivity and perceived environment. This can be done with a larger sample size and in different buildings and a wider range of both environmental and non-environmental factors can be assessed all at once.

In all studies that investigate factors affecting productivity, the metrics for measuring productivity will depend on the activities performed in the workplace. For instance in call centres, measuring call related output such as length of time to handle a call and wrap up time are relevant metrics for productivity. In a manufacturing industry or on the production line, length of time to complete task such as assembling of discrete parts are appropriate metrics. In offices where the activities are predominantly desk and computer based, the metrics for measuring productivity can be in the form of a paper-based or online survey. Metrics for measuring productivity must also include management related indicators such as employee sick leave and absenteeism (due to sickness) records and levels of staffing, overtime records and staff turnover, performance goals and expectations.

IEQ AND PRODUCTIVITY: EXISTING EVIDENCE

CEN standard EN15251 acknowledges that the indoor environment affects occupant productivity as well as health, comfort and so recommended limits are set for optimum performance. Factors that negatively influence productivity are to some extent easier to realise compared to those that have a positive impact. An environment that is too hot or too cold or too noisy can be uncomfortable or distracting to work in. The optimal level of IEQ parameters at which point productivity begins to increase is however more challenging to identify. Several studies have therefore been conducted to further understand and quantify the relationship between IEQ parameters and work place

productivity. Table 1 presents a summary of selected relevant studies reviewed and are further discussed in the subsequent sections.

Temperature and productivity

The effect of temperature on health and comfort has been widely researched and it is broadly recognised as an important IEQ factor. The recommended limits for Category II[5] mechanically ventilated office buildings in the summer and winter are 20°C and 26°C respectively. This implies that between 21 and 25°C, there are no direct risk to occupants' health and comfort. For naturally ventilated buildings, comfort indoor temperature is dependent on outdoor temperature with a much wider comfort band. The significant influence of indoor temperature on workers productivity was reported by Tham (2004) in the recommended ventilation rate and Witterseh et al (2004) in a quiet environment. Fang et al (2004) studied the impact of temperature and humidity on performance at 20, 23 and 26°C in 10l/s/person (recommended) and 3.5l/s/person (low) ventilation rates environments where participants were allowed to adjust their clothing levels to maintain thermal comfort. At 10l/s/person, difficulty in thinking and other SBS symptoms was highest in 26°C and lowest in 20°C. Interestingly, the experiment did not demonstrate any significant effects of IEQ on the tasks performed. In the study conducted by Lan et al (2011) with 12 participants in the same clothing level, in neutral and warm thermal conditions, with the exception of text typing, performance in all the other tasks performed was decreased in warmer conditions compared with the cooler conditions. With text typing, although more characters were typed at higher temperature, more errors were also made. The results from the study imply that thermal conditions for comfort may not necessarily match thermal conditions required for optimum productivity. From Seppänen et al's meta-analysis, the temperature range for optimum performance is close to the optimum range for comfort according to thermal comfort standards particularly for mechanically ventilated buildings in the winter season. In free-running buildings where comfort temperature is dependent on outdoor temperature and the comfort range is wider, there will be a bigger difference between optimal temperatures for comfort and performance and a 2% decrease in productivity for a 1°C will have significant cost implications for the organisation

[5] Category II buildings are described as 'normal level of expectation and should be used for new buildings and renovations'.

Table 6 Summary of selected, recent studies (intervention and observational) that investigated the links between IEQ parameters on workplace performance

Study	Study type and location	Procedure	Results
Tham (2004)	Intervention study in a mechanically ventilated call centre in Singapore (n=56)	A 2x2 experimental plan to investigate the effect of temperature (22.5°C and 24.5°C) and ventilation rate (5l/s/p and 10l/s/p)	11% reduction in call talk time when ventilation rate was increased from 5 to 10l/s/p. 15.5% increase in call talk time when temperature was reduced from 24.5°C to 22.5°C at 10l/s/p
Witterseh et al (2004)	Intervention study in a mechanically ventilated office in Denmark (n=30)	Participants exposed to three different air temperatures (22°C, 26°C and 30°C) and two different noise levels (35dBA and 55dBA)	3% decrease in performance in calculation tasks when noise level was increases. 56% more mistakes in task conducted in high thermal conditions
Fang et al (2004)	Intervention study in a mechanically ventilated office in Denmark (n=30)	Participants exposed to different combinations of temperature and RH (20°C.40%, 23°C/50%, 26°C/60%) and ventilation rates (3.5l/s/p, 10l/s/p)	Increase in SBS symptoms and difficulty in thinking in higher temperature. No significant effect of temperature and humidity on performance
Vimalanathan and Babu (2014)	Intervention study in a climate chamber India (n=10)	Participants exposed to three different thermal conditions (17°C, 21°C and 28°C) and three different light conditions (500, 700 and 1000lux)	Temperature accounts for 38.6% variation in performance and light accounts for 19.9%. Optimum level of temperature was 21°C and light was 1000lux improved workers productivity.
Lan et al (2011)	Intervention study in a mechanically ventilated office in Denmark (n=12)	Participants exposed to two different thermal conditions (22°C and 30°C)	Performance in eight out of nine tasks (typical of office work) decreased in high temperature, In text typing, number of characters typed increased in 30°C however more mistakes were made
Seppänen et al (2003), 2006)	Review of studies	Meta-analysis conducted on published studies which have investigated the influence of temperature on performance	Between 21-25°C there is no effect of performance. Updated analysis showed that the temperature range for maximum performance was 21-24°C. Linear model gives a 2% decrease in performance per 1°C increase in temperature above 25°C
Wargocki et al (2000)	Intervention study in a mechanically ventilated office in Denmark (n=30)	Participants exposed to three different ventilation rates (3, 10, 30l/s/p)	Overall performance increased by an average of 1.7% for every two-fold increases in ventilation rate from 3-30l/s/p (without considering the amount of time spent)
Park and Yoon (2011)	Intervention study in a climate chamber in Korea (n=24)	Participants exposed to three different ventilation rates (5, 10, 20l/s/p)	5% increase in accuracy of calculation tasks, 2.5% increase in text typing and memorisation when ventilation was increased from 5 to 20l/s/p
Allen et al (2015)	Intervention study in a climate chamber in the USA (n=24)	Participants were exposed to different CO_2, VOC levels and ventilation rates	13% - 21% decrease in cognitive function score in poor IAQ (400ppm increase in CO_2 and 0.5mg/m^3 increase in VOCs). 18% increase in cognitive function score in increased ventilation rate
Satish et al (2012)	Intervention study in a climate chamber in the USA (n=22)	Participants were exposed to different CO_2 (600ppm, 1000ppm and 2500ppm)	Relative to 600ppm, there were moderate to large decrease in decision making performance at 1000ppm and 2500ppm
Kajtar et al (2003)	Intervention study in a climate chamber in Hungary (n=10)	Participants were exposed to different CO_2 (600ppm, 1500ppm, 3000ppm and 4000ppm)	Relative to 600ppm there was significant decreases in the number of misspelled words identified in 3000 and 4000ppm
Fisk et al (2002); Federspiel et al (2002)	Field observation conducted in a call centre in USA	Average call handling time was recorded and indoor and outdoor CO_2, indoor temperature and RH were recorded for almost three months	Call handling times increased as difference in indoor and outdoor CO_2 increased above 75ppm. Between 21.7 and 24.5°C there was no effect of temperature on performance

IAQ and productivity

Parameters characteristic of IAQ are indoor air pollutants, ventilation rate, relative humidity and odour. A minimum ventilation rate of 10l/s/person is specified for office spaces. This ventilation rate is required to maintain comfort air quality and odour and corresponds to an indoor CO_2 concentration of 1500ppm and as CO_2 is product of metabolic process, it is often used as a proxy for ventilation rate. Threshold limit values and permissible exposure limits for other indoor air pollutants are set by international health organisations.

The study conducted by Wargocki et al (2000) and Park and Yoon (2011) showed that performance in text typing, addition and proof-reading increased in ventilation rates above the recommended. The effect of indoor air pollutants has also been demonstrated in intervention conducted by Allen et al (2015), Satish et al (2012) and Kajtar et al (2003), where participants were exposed to different levels of CO_2 concentrations (representing background and high indoor CO_2 levels).In all three studies, performance decreased as CO_2 concentration was increased with statistically significant decrements in tasks. In the study conducted by Allen et al (2015), as well as CO_2 concentration, the concentration of volatile organic compounds (VOCs) was increased above the recommended limit and this resulted in a 13% decrease in cognitive function score. Using the difference between indoor and outdoor CO_2 levels as an indication of ventilation rate in a call centre, Fisk et al (2002) and Federspiel et al (2002) found that when indoor CO_2 was more than 75ppm above outdoor levels, call handling times increased by 3.5%. These studies indicate CO_2 levels encountered every day in most spaces and CO_2 levels within the current recommended standards can have significant negative impacts on worker performance.

Milton et al (2000) and Fisk (2011; 2012) estimated the economic cost/benefits of increasing ventilation (and the resulting increase in productivity) in offices. Milton et al found that increasing ventilation rate from 12l/s/person to 24l/s/person reduced short term sick leave and they suggested that with the current recommended ventilation rate, lost productivity due to sick leave could cost as much as $22.8billion per year. In a theoretical study, Fisk et al (2011) estimated the economic benefits of improving IEQ by simulating four different scenarios, two of which were increasing ventilation rate to 10l/s/person and then to 15l/s/person. At 10l/s/person, the estimated annual economic benefit was $5.6billion and at 20l/s/person, it was $13.5billion. At 10l/s/person, performance was increased by 0.7% and at 15l/s/person, performance was increased by 1.1%. These accounted for approximately 75% of the economic benefit. In both scenarios, there were energy costs which accounted for 0.4% and 0.3% of the total benefits. These findings indicate that improving ventilation rates in offices can result in significant benefits for the organisation.

Noise and productivity

After amount of space and visual privacy, noise level has the biggest negative impact on occupant overall dissatisfaction with their workspace (Kim & de Dear, 2012). Acceptable ambience noise levels of 35-45dBA are specified for office spaces.. Different noise levels affect the comfort of building occupants, causing interference in speech and hearing and distraction from work. In Witterseh's (2004) study, they demonstrated that even at a realistic noise level of 55dBA, there were negative effects on performance of office work. They found that the differences in fatigue and difficulty in thinking in noise levels found in a typical quiet office and an open plan office were statistically significant and performance in addition task was significantly decreased by 3%. Noise distraction decreases performance of tasks that require concentration and also, level of noise distraction is dependent on the task being performed.

Light levels and productivity

Typical light levels recommended for office tasks are 300-500lux however this is task dependent. According to the Society of Light and Lighting (SLL) Light Handbook (2009), in paper-based tasks, the surface to be viewed will require an increased amount of light levels as opposed to computer-based tasks where the surface viewed is self-light emitting and so increasing light levels will make the surface less visible. Choi et al (2012) confirmed this in a study of 402 workstations in 20 commercial office buildings where they found that illuminance under 300lux was found to be satisfactory for computer work and for paper-based tasks, illuminance level above 500lux was satisfactory. The study conducted by the Heschong Mahone Group (Davis, 2003) was focussed on the contribution of windows and daylight on improvement in office and call centre workers performance. With the office workers, they found that glare from the windows decreased the performance of computer-based tasks by 15-21% but higher levels of daylight were found to have positive effects on tasks measuring attention span and short term memory. From their results, they suggested that workers are more sensitive to changes at lower levels of daylight illumination and progressively less sensitive at higher levels.

PERCEIVED ENVIRONMENT, CONTROL AND PRODUCTIVITY: INSIGHTS FROM BPE PROGRAMME

The studies discussed in the previous sections have shown the influence of the physical environment on productivity. Specific levels or ranges of selected IEQ factors have been investigated and their impacts on productivity have been demonstrated. Lan et al (2011) showed that the mental performance of subjects who were clothed for comfort at temperatures of 18.7°C and 23.2°C was unaffected by temperature. This implies the importance of considering contextual factors when investigating productivity.

The following section reports on the analysis of surveys conducted to assess occupant satisfaction with the building and environments they work in. The survey was conducted as part of Innovate UK's BPE programme. The focus of the BPE programme was on the building's fabric performance, energy consumption, environmental performance and occupant feedback and satisfaction. The case study buildings were leading-edge, low carbon buildings. They were intended to demonstrate sustainable design through high levels of airtightness, novel ventilation systems and effective controls.

Results

From the 21 projects, 12 projects reported an increase in perceived productivity. The maximum increase in productivity was 10% and the average was 4.9%. This increase in productivity is due to the overall environmental conditions perceived by the occupants as opposed to an increase in productivity due to a change or an intervention. Comparing to the BUS international benchmark for non-domestic buildings, productivity increase in nine projects was above the benchmark and in three projects, it was not different from the benchmark. The proportion of variance in perceived productivity explained by each variable is presented in Table 2 for variables in which the regression models were statistically significant ($p<0.05$). From the results, when air was perceived as stuffy and smelly, perceived productivity decreased and when occupants were satisfied with temperature (only in the summer), noise and lighting conditions and with building related features, perceived productivity increased.

Table 7 Proportion of variance in perceived productivity explained by the rated variables

Variables	r^2
Air in summer: fresh/stuffy	0.47
Air in summer: odourless/smelly	0.35
Air in summer: overall	0.51
Air in winter: fresh/stuffy	0.38
Air in winter: odourless/smelly	0.39
Temperature in summer: overall	0.46
Noise: overall	0.23
Lighting: overall	0.50
Overall comfort	0.72
Design	0.54
Needs	0.28
Image	0.43
Space in building	0.35
Cleaning	0.32
Safety	0.46
Furniture (usability)	0.58

From the analysis of the survey results, none of the perceived control variables were significantly related to perceived productivity. Control over cooling and heating was actually negatively correlated with perceived productivity indicating that as the level of perceived control increased, perceived productivity decreased. Given the differences in optimum temperature for performance, it can be assumed that the provision of personal control of thermal conditions may be an ideal method for improving performance. The contradicting findings from the BPE study may imply that effect of personal control may be dependent on the environment and the type of activities performed. Further research is required to explore this in more detail.

Occupants also rated their perceived health in the building and feeling healthier in the building accounted for 61% of the variation in an increase in perceived productivity. IAQ has direct effects on occupants' health as sick building syndrome symptoms increase in poor IAQ. Perceived health will therefore have an impact on productivity. The results confirm the findings from studies conducted by Wargocki et al (1999; 2002) and Lee and Guerin (2009). Initial analysis of the Leesman survey on workplace effectiveness has also shown the importance of contextual factors performance. Alongside factors such as IEQ parameters, furniture and space, they found significant differences in workers age, time with organisation, work setting and activity profile on workplace satisfaction (Leesman Ltd., 2016). These findings all show that a wider range of factors need to be taken into consideration when assessing productivity in the workplace.

DISCUSSION

The present literature survey is a part of an innovative research project on controlling workplace environments to improve occupant productivity. The literature survey intended to highlight the links between IEQ and productivity, approaches used to investigate this relationship and the metrics used to measure productivity with focus on commercial offices.

Some of the studies reviewed used intervention tests in both climate chambers and real life workplaces to examine the effect of different IEQ factors on productivity. In intervention studies participants are blinded to the conditions created and so fair comparisons can be made between the baseline and the created conditions. The limitations of interventions studies are that the controlled conditions are often not representative of real life working environments where IEQ factors are constantly changing. Also in intervention studies where participants are asked to complete specific tasks, they may be overly enthusiastic or motivated and may perform better even in poor IEQ conditions, affecting the results of the study. In observational studies and occupant surveys, occupants in their normal place of work are asked to provide feedback on their environments and perceived productivity. This is an effective method for collecting a wider range of information from a large sample size (from multiple buildings). However, self-reported assessments of the environment and productivity may not be entirely reliable. The BUS questionnaire for instance asks occupants about perceived air quality and temperature in the summer and winter. Although the outdoor climate influences indoor conditions, occupants may not be able to provide accurate feedback on conditions that occurred in the past. Where possible, monitoring of IEQ parameters can be carried out in order to validate the survey results.

Indicators of workplace performance have included actual task output in organisations such as call handling time in a call centre and file/records handling time in an insurance company. In the intervention studies, specific tasks which are deemed as typical of office workplaces have been administered to participants. However, in most offices, these tasks are not usually monitored or measured. In such workplaces, measures of productivity are more complex. Human resource information such as sick leave and absenteeism due to the working environment may be more appropriate for measuring productivity. Also, performance goals can be defined which can then be monitored as a metric for 'presenteeism' (productivity when present at work).

The studies reviewed have highlighted the important role of IEQ parameters on productivity. The improvements in IEQ parameters which are necessary for improving productivity are also characteristic of low energy/energy efficient buildings. Improving thermal conditions, ventilation rates and IAQ to provide healthy indoor environments have significant cost benefits which outweigh the energy costs of the building. Hence improvement in occupant comfort, health and productivity can be achieved without significantly increasing the energy cost of the building. As well as IEQ factors, contextual factors have been highlighted as having significant effects on productivity. Perceived environment and control, personal and social factors all need to be taken into account when assessing workplace productivity. In order to provide environments that are satisfactory to occupants and enhance productivity, it is important to understand how all the different factors influence the environment. The environmental and contextual factors and the performance metrics should be relevant to the environment being reviewed.

Results from this study will be used to design a monitoring specification for data collection from a number of commercial office buildings. IEQ data from the monitoring trial will be analysed alongside productivity data, and empirically tested to understand how changes in environmental conditions impact on occupant performance. Results of the data analysis will be used to produce a dynamic control model that will be tested in a number of trial buildings. By integrating the dynamic control model into the building management system it should be possible to reduce energy usage through optimisation of existing building services in a demand led intelligence based system. The completed WLP+ solution aims to reduce building energy use by 30% while increasing productivity by 10% and improving occupant comfort and wellbeing.

CONCLUSION

By reviewing existing literature, this paper has identified the metrics used in measuring productivity in office environments and highlighted the impact of IEQ variables on work place performance. Research methods used to investigate the impact of IEQ on productivity include intervention studies in laboratories where participants are exposed to controlled conditions whilst performing specified tasks or in observational studies using questionnaire surveys to record self-reported productivity. Typical office tasks and processes such as text-typing, simple calculations, speed of work completion and accuracy of results are not often representative of the multitasking required in real office environments. Other indicators of productivity such as absenteeism, staff turnover and frequency of sick leave must be included when assessing work place productivity.

IEQ parameters characterised by temperature, IAQ, noise and lighting conditions all have significant effects on occupant comfort, health and wellbeing. These environmental parameters have been found to have significant effects on work place productivity resulting in significant cost implications, as the people cost in buildings far exceeds the energy and operation costs. Findings from existing studies show that environmental parameters differing from the recommended limits have positive effects on productivity (i.e. higher ventilation rates and lower CO_2 concentrations). Findings from other existing studies suggest that contextual factors also have an effect on productivity. Perceived environment and building related factors recorded through questionnaire surveys have shown significant effects on productivity. By analysing the BPE BUS questionnaire database, the relationships between both environmental and non-environmental variables was assessed. As well as perceived air quality, temperature, noise and lighting, overall comfort in the building, satisfaction over building design, work space and furniture have been shown to be significantly linked to perceived productivity.

The findings from the literature review and the BPE BUS analysis show that the performance of single measureable tasks due to single environmental conditions only bears limited links on productivity. Rather, a much wider scenario should be considered. As well as this, static environments are not representative of actual working environments. Variation and changes in the indoor environment over time should be considered when investigating productivity in work places. Having demonstrated the influence of environmental factors on productivity there is now a need to improve the physical conditions in office buildings. WLP+ aims to develop a dynamic environmental control model for optimising IEQ in commercial office buildings to improve occupant productivity and reduce energy use. The model will be validated through implementation, monitoring and analysis of multiple socio-technical parameters and multiple metrics for measuring productivity in selected case study buildings.

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Energy and Management

MONITORING THE ENERGY CONSUMED BY A NETWORK INFRASTRUCTURE TO DETECT AND ISOLATE FAULTS IN COMMUNICATION ARCHITECTURE

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ABSTRACT

In recent years, a number of major improvements were introduced in the area of computer networks, energy-efficient network protocols and network management systems. Software Defined Networking (SDN) as a new paradigm for managing complex networks brings a significant opportunity to reduce the energy consumption among ICT. In this paper, we are tackling improvements in the process of monitoring the states of the networking devices and optimizing the existing solutions. We are monitoring the energy consumption of a network architecture and augment the retrieved raw power data to detect changes in the state of the devices. The goal is to benchmark the difference between the power data fetched from the real-measures and the data extracted from the power models, translated as the expected behavior of the devices. An application is designed to monitor and analyze the retrieved power data of a simulated ICT infrastructure composed of Cisco switches and routers, Dell Precision stations and Raritan PDUs. Moreover, smart algorithms are developed which outcome results with detection of changes in the state of the devices, as well as with detection and isolation of possible anomalies and their impact on the energy consumption. The application is envisioned to be an extension to the existing SDN controllers for monitoring and reporting the changes in the state of the ICT devices.

INTRODUCTION

The energy-efficient network infrastructures have recently become a hot topic in the business world, as the concept of Green IT strives to reduce the overall operational costs, but in the same time also to eliminate the inefficiencies from the enterprises' IT systems. The network infrastructures are already massively deployed and even projected to have exponential growth (Cisco, 2011) due to the evolution of the Internet, user demands and trending topics such as Internet of Things (Ovidiu and Friess, 2013). Thus, as a shared resource they have to be constantly available, which exacerbates the sustainability issues. Researchers have already proposed different network-wide energy management schemes targeting various areas such as datacenters (Koutitas, 2010), mobile networks (Wang et al., 2012) and WANs (Gupta and Singh, 2003). However, it is quite challenging to tackle the energy efficiency issues within the households and from small to large enterprises. One obstacle in making enterprise networks more energy efficient is the range of devices from multiple vendors deployed on the network. Also, it is difficult to operate with enterprise networks because of their unpredictable growth, frequently changed topology and architecture, regarding the energy consumption.

Current research and developed Network Management Systems (NMS) are not fully automated when executing energy-efficiency policies. The introduction of SDN paradigm brought new opportunities for managing networks through abstraction of lower-level functionality. This means that a centralized SDN controller with only one transaction is able to reconfigure a group of devices. However, the monitoring process of existing NMS to report for changes in the state of the devices is based on point-to-point (p2p) communication with every device on the network. This creates a great deal of traffic and puts additional burden on the network, which raises a sustainable issue in complex networks. Due to improvements in the field of Green IT and smart meters, it is feasible to build a NMS that recons only on power data fetched from the power distribution unit. A pattern for augmenting the values extracted from the power consumption of the network could provide useful information about different network states, for instance detecting changes in the topology. The idea is to use Fault Detection and Isolation (FDI) approach to monitor the network state based on the energy usage. Figure 1 shows that we need two information, a model representing the expected behavior of the devices and the real-time measurements to analyze deviation between the two processes. A deviation corresponds to fault detection in the network, which is in a form of misconfiguration or improper use of the equipment. This means that monitoring the energy consumption could be used not only for Green IT purposes, for raising awareness and reducing the electricity costs, but as well for a classical ICT monitoring system. Also, as the concept of Smart Grid is making use of digital networks to improve the transportation of energy, the work presented in this paper could be explained as the reverse process -how the use of energy could improve the data transport.

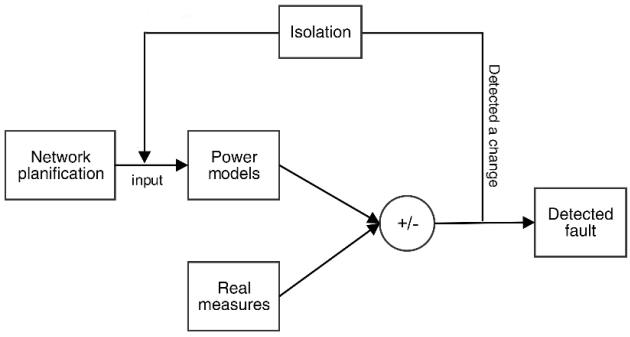

Figure 1. The general approach of the paper

The remaining part of this paper is organized as follows: Section 2 presents the related work, while the Section 3 presents the objective of the paper. The system is described in Section 4, which includes the architecture for network management, the design of the experiments and the implementation of the developed application. In Section 5 the obtained results are presented and discussed, while the Section 6 concludes the paper.

RELATED WORK

In recent years a new approach for network management emerged under the name of Software Defined Networking (SDN) that allows the network operators to manage the network services through abstraction of high-level functionality. A study by (Kim and Feamster, 2013) proposes an event-driven network control framework based on SDN paradigm and OpenFlow protocol to manage a complex campus network. The focus is on enabling frequent changes to network conditions and states, providing support for network configuration in high-level language, and providing better visibility and troubleshooting. Having a global knowledge of the network state, the developed control framework introduces a centralized approach for network configuration, opposed to distributed management. Meaning that the network operators will not have to configure all the devices individually, but instead let the software make network-wide traffic forwarding decision from a logically single location. Moreover, the network operators provide high-level network policies which are translated by the controller in a centralized manner into a set of forwarding rules, which are used to enforce the policy on the underlying network equipment, by using OpenFlow, as depicted on Figure 2. They offer a set of control domains which can be used by the network operators to define conditions by assigning a suitable packet forwarding actions which corresponds to each condition. Even though the proposed solution reduces the workload of network configuration and management due to the SDN paradigm, the study mainly focuses on the algorithm for translating the policies into a set of reconfigurations of the devices. The system is based on event sources that dynamically collects the current state of the devices, which are inputs to the controller for forming the policies. The event sources monitor the network state and report the changes to the controller, such as bandwidth usage of every end-host device. The monitoring is based on the SNMP and OpenFlow for pulling data with p2p communication which is difficult to manage especially during an expansion of the network, when adding new devices to the network, or during changes to the physical network topology which alters IP address modifications.

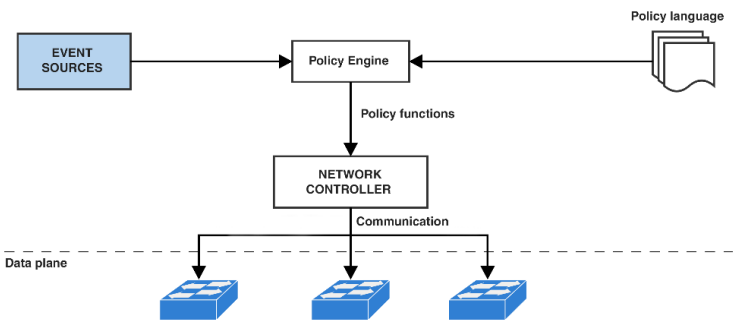

Figure 2. Classical SDN architecture

The strategy presented in (Aubrun at al., 2008) for studying the effects of unknown induced delays in network architecture suggests the use of concepts such as Fault Detection and Isolation (FDI) and Fault Tolerance Control (FTC). The study defines a threshold for the expected delay on the basis of the network characteristic and network calculus theory. A faulty situation is then generated and compared to the defined threshold in order to successfully detect which elements are causing the delays and deals with them in a controlled manner. Similarly, (Riekstin et al., 2016) proposes the use of power profiles for each device on the network to determine their expected energy usage under different circumstances. However, the power profiles are considered in special case when the real-time energy measurements are not accessible. They suit as a backup figure to proceed with the FDI's calculations to determine a faulty situation and produce energy efficient policies for the network.

The study by (Drouant et al., 2014) proposes models that gives a global overview of the impact that the network and the ICT equipment is having on the environment, developing the following equation:

$$E = E_m + E_u + E_d$$

$$E_m + \int_{t=0}^{end\ of\ lifecycle} Pu(t)dt + E_d \qquad (1)$$

Where E_m is the energy required for manufacturing and transportation of the equipment, E_u is a factor related to the energy consumed during the usage of the equipment, and the energy required to dismantle the equipment is E_d. For the second part of (1), *Pu* is related to the power consumption by the network architecture during its use phase.

Two strategic approaches exist for modeling the energy consumed during the usage phase of the devices. The first involves a high-level modelling (Foll, 2008) of the whole architecture and the second approach is more precise, meaning that it provides power models for each of the devices part of the network. A high-level model has less interactions with the devices and therefore fails to give accurate estimations how much energy a network architecture consumes at a particular point of time. On the other hand, the use of energy consumption models developed for a particular device would require constant p2p interactions and cause certain amount of additional traffic in the network. However, by giving a more precise figure on the expected behavior of the devices the system would be more responsive to minor changes, faults and anomalies, which is the purpose of the experiments part of this paper. Therefore, the power models for Switch (Reviriego et al., 2012)(Hossain et al., 2015), Router (Ahn and Park, 2014), PC (Agarwal et al., 2009) and Access Point (Demir, Kurt and Karaca, 2014) are added to the Power Model Registry, as shown on the Figure 5, explained in the next sections.

OBJECTIVE

The goal is to develop sustainable software application suitable for network monitoring systems, which operates only with the retrieved energy consumption data from the ICT devices part of the network infrastructure. The developed application communicates with the Power Grid illustrated on the Figure 3, and by following the FDI approach shown on the Figure 1 is able to detect different states that are occurring on the ICT devices. The network of the power grid includes the Raritan Power Distribution Unit (PDU), which provides the real-time measures for the energy consumption through SNMP periodic pulling. With this, the PDU grid forms the power monitoring process. The detection of the states is achieved by the developed application, which analyzes the retrieved raw power data to distinguish possible faulty situations and anomalies in the usage phase of the ICT devices. The output of the application, or the detected new state suits as an input parameter to the SDN controller. This means that the developed application is envisioned to replace the classical event sources, part of Figure 2, which are using point-to-point communication to report for changes in the state of the devices. To achieve this, the developed software requires two information to be considered: (i) power data from *real-time measurement* procedure and (ii) values for the expected power consumption of each device extracted from the *power models*.

(i) The process of *real-time measurement* requires probes and standardized protocols to access the needed metrics which are altogether coupled in a monitoring system. In practice, Raritan Power Distribution Unit (PDU) is the monitored equipment which has a predefined energy Management Information Base (MIB) as a hierarchical structure with properties that is pulled out periodically. The monitoring system itself is then able to collect, analyze and modify the information stored in the MIB through SNMP. It is important to note that the PDU in this case acts as a separate network from the existing network architecture. This means that the monitoring process has a separate channel to the PDU and the packets does not cross the existing network architecture, which releases the burden on the network.

(ii) From the other side, as discussed in the section II, the selected *power models* represent the expected behavior of the equipment. Therefore, currently there is an open field to combine the real-time measures, which are translated to the real behavior of a device, with the developed models. A deviation between the models and the monitored power data is used to detect anomalies and to anticipate fault according to a trend analysis.

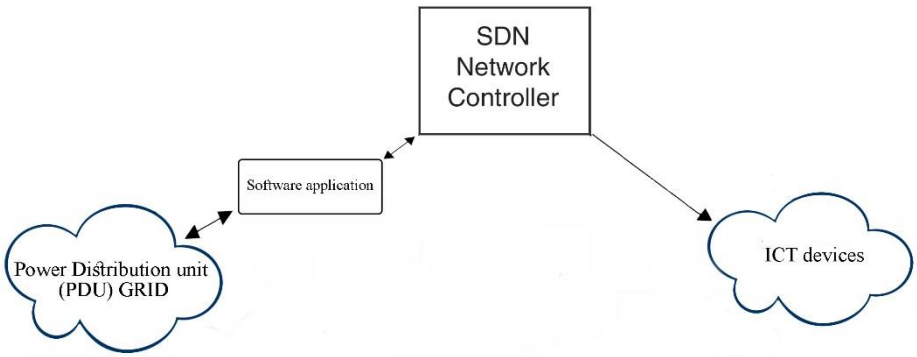

Figure 3. Objective of the developed system

The output of the developed system is a continuous detection of changes in the network infrastructure, for instance detecting new device on the network, changes in the Spanning tree

protocol, detection in changing the operating state of a switch port, etc. Finally, the objective is the developed monitoring system based on the power grid as shown on the figure 3, which will be a replacement for the existing monitoring system in (Kim and Feamster, 2013) which does a p2p communication with every device part of the network.

Building a knowledge base

The developed application that incorporates the monitoring system and the power models has to form thorough foreknowledge in order to successfully anticipate and interpret the readings for the energy consumption. Mostly because the power data is just a raw value and does not contain rich information. As suggested by (Kazandjieva at al., 2013), some types of computing systems within the enterprise can exhibit large variations on the power data even when comparing two instances of the same device model. More precisely, two Dell Optiplex 760 PCs were observed to have over 40% discrepancy in their average power draw. To remedy this, the application has to augment new ways to isolate the problem with the inconsistent energy consumption of the devices, to locate the fault or the anomaly and to classify the problem. One way to deal with this is to predict the fault that may occur during the usage of the equipment. It is important to test the responsiveness of the application by generating different faults and misconfigurations that may occur during a typical workday in an enterprise network. Thus, closely observe the figures for energy consumption and build a knowledge base. A system with such knowledge comprised with smart algorithms is capable of analyzing the deviations and benchmark the faulty situations. From there a pattern could emerge to later detect the problem of aberrant values regarding the energy consumption of the devices during the real-life usage phase of the equipment.

List 1 represents the states which are chosen as most common during a typical enterprise workday, tested on a various heterogeneous combinations of network architectures, prior building the knowledge base. To identify where the faults are applied, a classification based on the objective is depicted on the Figure 4.

List 1: states to be detected on the network

Testing the operational vs. the sleeping mode on the devices such as switches, routers, access points, LCD monitors, PCs and laptop computers

Turning off/on a switch port

Performing link adaptation on the switch's ports

Evaluating the effect on Energy-Efficient Ethernet (EEE) and Cisco EnergyWise

Testing a Spanning Tree Protocol (STP) reevaluation on the network

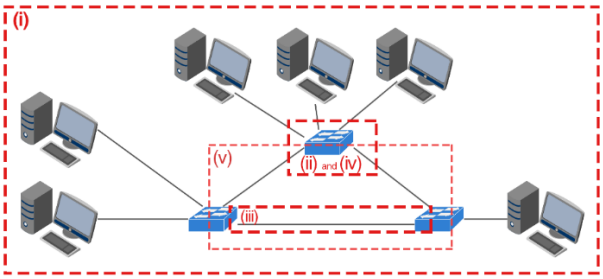

Figure 4. The classification of the faults

One possible case study of network architecture is depicted on Figure 5, where the generated faults are represented as the *'Y'* input parameter. At disposal for the experiments there were 8 Cisco switches from the series 2960 and 3560, 8 Cisco 1941 Routers, 10 Dell Precision T1700 stations, 2 HP Pavilion laptops, 6 Raritan PX2 PDUs and 2 Raritan PX3 PDUs.

The logic behind the monitoring system

The states illustrated on the Figure 6 represent the logic throughout the execution process. Having developed a standalone application able to monitor the energy consumption as a first state allows further analysis process on the retrieved and stored data. The analysis engine as a second state is tightly coupled with the learning model of the system by developed smart algorithms which are able to detect and identify the changes in the power data. Big part of the analysis process plays the inclusion of the power models, discussed in the related work, which are defining the power profiles of the devices and are calculating their expected behavior. The output of the models is then validated

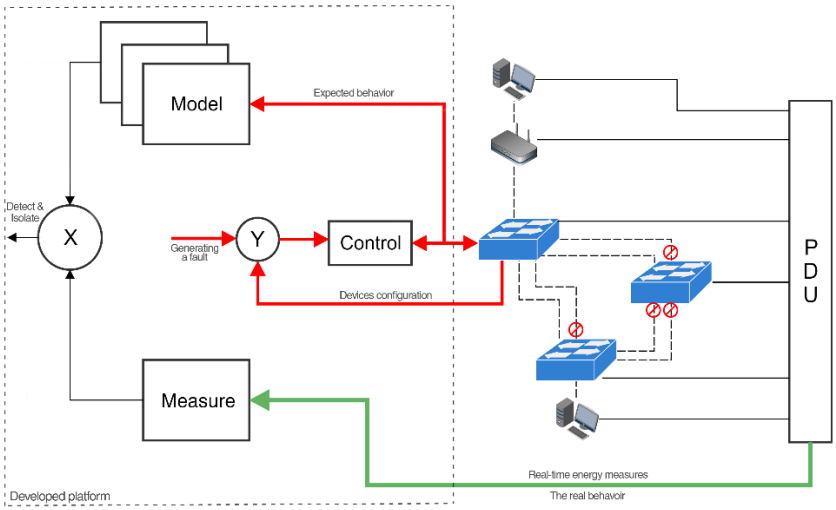

Figure 5. System behavior

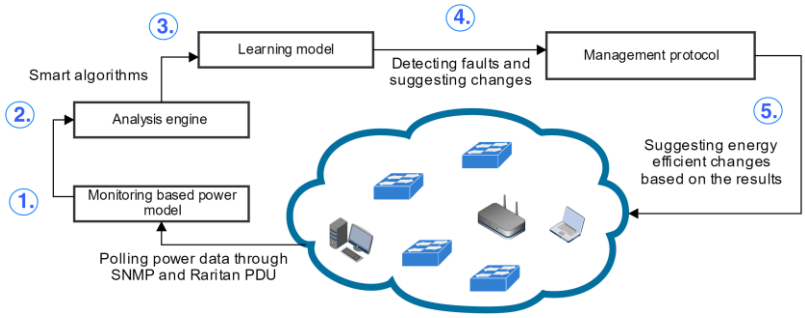

Figure 6. The experiment's logic

with the retrieved real-time measurements for possible deviations. Raritan PDU offers the possibility to monitor its overall consumption as well as the individual power consumption per socket. This means that if a deviation is detected in the comparison process of the overall consumption, the analysis engine will further seek for the device causing the energy disparity. A recent history of energy consumption is retrieved from a database for the detected device and the results are logically passed to the third state, where they are further dismantled towards understanding and interpreting the power data values. The emphasis of the third state, the learning process, is given to the simulation of the faults that are most frequent during the regular usage phase of the ICT equipment. The established knowledge base is used as a baseline on which the learning model is constructed. This means that series of experiments have to be conducted for a range of different network states and faults in the interest of acquiring the desired foreknowledge to benchmark the anticipated states. The benchmarking process is also the key concept for the isolation part as a last state of the logic depicted on the Figure 6.

Ever since the commencement period of the learning process, the system is constantly updating its knowledge base depending on the behavior of the devices, and by following the figures for the energy consumption it is able to discern the aberrant states of the devices. For instance, a possible overloading on the devices, detecting sleep/hibernate states, physical or logical changes in the configuration of the devices, etc. To have seamless operations and accurate output, the learning process also needs to update the static values in the power models based on the detected new state of a particular device. Namely, as seen on the Figure 1, the equations in the power models depend on static parameters from the network planification, which are gathered during one-time measurement. This means that the learning model has to re-compute the input parameters in the power models after a detection of a new network state. For instance, the equation in the power model of a switch has to be updated with new value if a switch port transitioned from offline to online state and vice versa. The outcome of the learning process regarding the benchmarking part concludes the fourth state of the logic behind the experiment, the engine for power management. An accurate benchmarking provides the possibility to identify the changes that occurred on the network infrastructure and suggests a recuperation, or a reconfiguration of the network.

SYSTEM DESCRIPTION

This section provides more technical explanation of the developed application. The architecture of the system has been previously described in (Minovski, Rondeau and Georges, 2016).

Implementation

The application, which includes the power models and the monitoring module is implemented in Java language using the SNMP library and MySql database. The energy monitoring task is developed in a multi-threaded fashion to periodically pull the energy values from the Raritan PDU, by importing Java libraries for SNMP to access the functions for requesting the right Raritan's MiB OIDs. There is an ability to optimize the frequency of the probes send to the Raritan PDU throughout a developed GUI, thus the accuracy of the measures is practically defined by the operator. During the test phase of the application, probes were requested every second and the responses are stored locally with the interest to enable further analysis on the data. The response from each probe is a group of values in the following format: $I_{(A)}$ – *Electric current significant with* 10^{-3} *amps (A) base*; $V_{(V)}$ – *Voltage*; *PF – Power factor*. To get the current energy consumption (W) the following equation has to be performed:

$$W = I_{(A)} \times V_{(V)} \times PF \qquad (2)$$

Moreover, the probe response does not only contain data for the total energy consumed by the whole PDU, but also it reports the consumption of each socket individually. This means that the application with additional analysis can successfully build its own schemas and detect what kind of device is connected to a certain socket. Giving this ability, the process flow can successfully discover which device specifically is not consuming the energy as it is expected. Algorithm 1 describes the process flow of the application.

Algorithm 1: the process flow

input: PM, the power models; PR, the probe response
output: F_{fault}, detected fault, $I_{isolation}$, isolating the fault

R is the Raritan PDU
E denotes the attached equipment
KB represents the knowledge base in a form of database

```
foreach X in PR do
    W_total ← X(I_(A)) * X(V) * X(PF)
    Store(W_total)
    if W_total > PM_total then
        foreach E in R do
            W_individual ← E(I_(A)) * E(V) * E(PF)
            Store(W_individual)
        if W_individual > PM_individual then
            F_fault ← Detection(E, KB, History(W_individual))
            I_isolation ← Isolation(F_fault)
            Store(F_fault, I_isolation)
return F_fault, I_isolation
```

The support of power models (PM) in the application creates the premises to set the expected threshold regarding the energy spent by each detected device. The discussed power models are represented with a static parameters gathered by one-time measurement at the initialization phase of the application or when a new device is plugged to the PDU socket.

Having a real-time availability probes enables the application to perform parallel comparison on the retrieved data for individual sockets, and as a whole, with the data provided by the power models. In case of aberrant values, the application tries to locate the device with the unexpected behavior, load the latest stored power data history of the device and perform analysis for fault detection. The FDI concept is based on calculations directed by the predefined fault foreknowledge, achieved by the experiments for generating the faults in order to benchmark the consumption that a particular occurring state is causing. The knowledge base (KB) is also integrated in the algorithm in a form of a database.

The Detection() function is the core of the algorithm due to the fact that it couples the analysis and the learning process, described in the previous section. It begins by locating the device that is observed to have disparity in the energy consumption. Also, a recent history of the spotted device is passed to the function, which includes two separate components. First is the recent energy consumption history of the device and secondly is the recent history of the noted running states and configuration of the device. This process maps the previous running configuration and understands the current states of the devices that might be causing the energy disparity. Moreover, the knowledge base is as well loaded which can interpret the difference in the expected and the real energy measures into a new network state. The function combines the above mentioned parameters and the calculations result with detection of the changed state. For instance, a switch is detected to have powered off a port, changed the link speed, or perhaps reevaluated the STP.

The Isolation() function as a input parameter receives the detected new state and performs further analyses to examine the implications, especially on the energy consumption. The analysis determines the actions that have to be taken upon detection of new state. For instance, if a switch port is detected to transition from online to offline mode, this function re-computes the input parameters of the static power models to make them having accurate calculations of the expected energy consumption of the switch. This means that the examination of the implications result with discovery whether the detected new state is a misconfiguration of the network, a faulty situation or just changes in the network state that have to be noted. As an output, the Isolation() function updates the database of the spotted device recent history and the knowledge base, and reports to the network operator for the changes.

The first version of the GUI is show on the Figure 7. The network operator is able to see live chart of the energy consumption of the whole network, as well as select specific PDU and monitor the consumption. Based on the detected states, the network operator could map the running configuration of the whole network, as well as separately for each PDU. When a specific PDU is selected, the operator could monitor the individual sockets, see the detected device and read the changes in the state. There is a possibility to download a report with a complete history of the changes on the network. The obtained results are discussed in the next section.

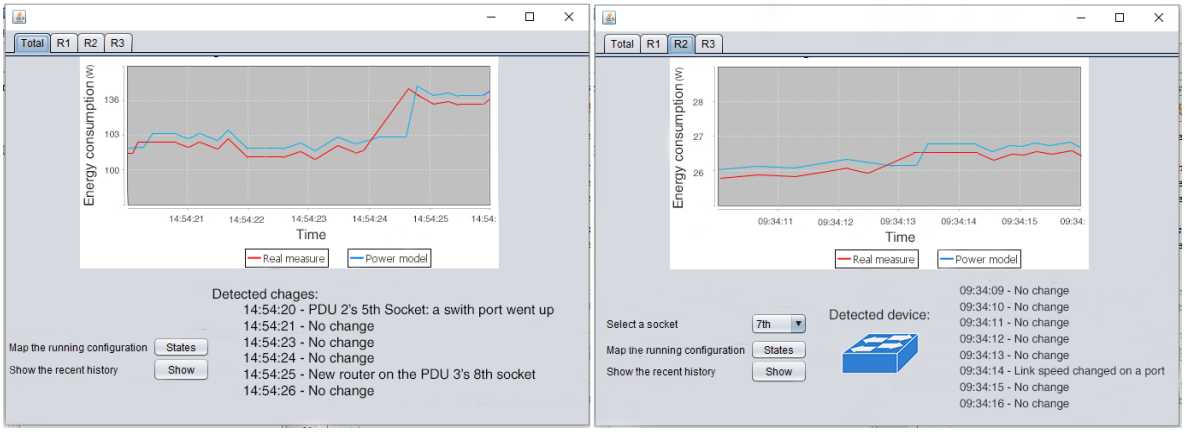

Figure 7. Developed GUI

RESULTS AND DISCUSSION

This section refers to the List 1, presenting the obtained results during the test phase of the developed application. Each of the experiments were tested on different network architectures, monitored for 10 minutes continuously, as well as under different amount of load generated to flow through the network. ***(i)*** The possibility to automatically detect the working hours of an enterprise allows the application dynamically to report on the equipment that was left in an operational state. For instance, if a wireless access point is observed to consume constant level of energy during non-working hours, the application will indicate that the device is powered, but does not transmit any data, meaning that it should transition into a sleep mode. The cost of powering the hardware components of each device dominates the overall power profile and therefore the opportunity for energy savings are the highest. The difference in the energy consumption between the operational and the sleeping mode is illustrated on the Figure 8. Typically, there is a burst of energy consumption when a device goes to operational state, either from sleep/hibernate or offline mode. Those values are also used to benchmark the current state of the device.

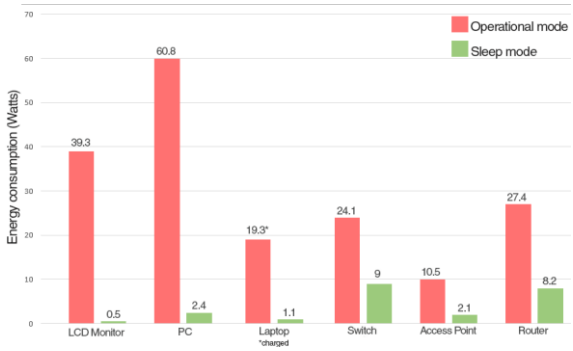

Figure 8. Obtained results – experiment (i)

(ii) Managing the active ports on a switch is one important and exquisite objective because it is the only way of providing network accessibility. Therefore, to have an overview on the status of the ports at one point of the time by observing the switch's values for the energy consumption is a delicate task. Mainly because of the introduction of EEE as a set of enhancements able to dynamically put a single link temporarily to sleep when not in use. The difference in the power consumption after a transition from active to inactive switch port is observed to be from 0.3 to 0.4 W, as illustrated on the Figure 9. This result allows the developed application to benchmark the state and have detailed matrix of the

port statuses of each switch. Having this feature allows issuing reports for possible unnecessarily active ports, but also is part of the analysis for a possible misconfiguration of the network.

(iii) The utilization of the Ethernet links is, on average, extremely low (Gunaratne et al., 2008). This suggests that there is an ample opportunity for energy savings by operating Ethernet links at a low data rate for most of the time with no perceivable performance impact to the user. To keep track of the each switch's port assigned speed, by following the energy consumption, means an opportunity for adjustments according to the needs. But it also helps the application to correlate the assigned link speed with the congestion, or the load on the switch, which is as well affecting the overall power consumption. During the observations, there is no notable change in the consumption when comparing 10Mb/s to 100Mb/s speed link, but the difference when making a transition from 1Gb/s to 100Mb/s is from 0.2 to 0.4 W per port. Thus, the developed application by benchmarking this value is forming a schema of each port link speed that is assigned. The outcome is a suggestion when to reduce the speed of a link when a low utilization is perceived.

(iv) Energy-Efficient Ethernet is not yet a feature supported by many network devices currently on the market, however it is important to observe its impact on the energy consumption. During an idle period of a switch with no traffic flowing through the ports, EEE will put all of the active ports in the Low Power Idle (LPI) state, and therefore achieve the same result as the second *(ii)* experiment of 0.3 to 0.4 W savings per port. Hence, the developed application has to be aware of the possibilities of EEE to dynamically, for a temporary time, put a port to idle mode.

(v) Spanning Tree Protocol (STP) is commonly used Layer 2 protocol that runs on switches and bridges, with purpose to ensure that there are no loops created on a redundant paths in the network. By default STP dynamically manages the elimination of the loops with the process of electing a tree based on priorities with a particular switch as a root. This means that there is a possibility of a network reconfiguration without the assistance of the operator, which could lead to additional power demands if it is not well managed. STP, enabled between the switches on the Figure 6, does not save any energy with its ability to block certain port in order to discard the loops in the network. Namely, a port in a blocking state is consuming the same amount of 0.4 W as the other active ports. The only noticeable difference is the spike of energy consumption when STP is trying to re-evaluate the tree. Namely, during a physical or a logical generated error, STP will elect a new root and construct the new tree, thus will add up to 1 W for few seconds to the overall consumption of the switch, depending on the architecture. This burst of energy, also shown on the Figure 9, is used to benchmark a change in the STP, with the interest of reporting it for possible misconfiguration of the network.

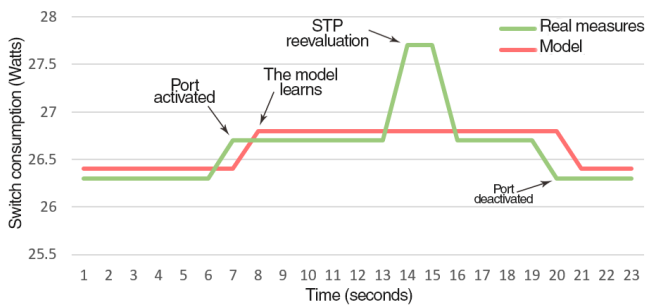

Figure 9. Obtained results – experiments (ii) and (v)

CONCLUSION AND FUTURE WORK

This paper presents the achieved results from evaluating the proposed novel extension for energy-efficient network management application emulated in a heterogeneous network environment. The results shows that a reliable application can be designed to monitoring the changes in the state of the devices with minor impact on the network regarding the traffic. The proposed monitoring process is designated as a replacement for the existing p2p pulling process, part of the SDN typical systems. The SDN controller, and thus the network operator, has the ability to receive reports for the changed state of the network in an energy-efficient way by following the energy consumption of the network infrastructure. The approach of monitoring the power consumption directly from the PDU, instead of p2p communication with every device, brings own complexity as the network grows. For instance, in a scenario of multiple faults happening simultaneously, the FDI concept presented in this paper is able to cope with the occurring situation. This is achieved by the possibility of following each PDU's socket individually from a centralized application. The support for real-time availability calculation enables the operator to take service-centric decisions, rather than network centric as proposed currently in the literature.

As future work, we envision a deployment of the proposed application as part of a SDN controller. Moreover, the application should be scalable in terms of network size and adapt to any SDN software controller developed on different programming language, with diverse libraries. The anticipation is also to include other common network anomalies and to follow their impact on the energy consumption, for instance the packet loss rate and highly congested networks, which could possibly trigger a use of other techniques in order to gather all the necessary information for the analysis process, rather than just monitoring the energy values.

ACKNOWLEDGEMENT

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REDUCING ENERGY CONSUMPTION OF NETWORK INFRASTRUCTURE USING SPECTRAL APPROACH

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Keywords: Green Networking, Energy Efficient Design, Spectral Clustering Method, Switch Hibernation.

ABSTRACT

The energy consumption by ICT (Information and Communication Technology) equipment is rapidly increasing which causes a significant economic and environmental problem. At present, the network infrastructure is becoming a large portion of the energy footprint in ICT. Thus, the concept of energy efficient or green networking has been introduced. Now one of the main concerns of network industry is to minimize energy consumption of network infrastructure because of the potential economic benefits, ethical responsibility, and its environmental impact. In this paper, the energy management strategies to reduce the energy consumed by network switches in LAN (Local Area Network) have been developed. According to the life-cycle assessment of network switches, the highest amount of energy is consumed during usage phase. The study considers bandwidth, link load and traffic matrices as input parameters which have the highest contribution to energy footprints of network switches during usage phase and energy consumption as output. Then with the objective of reducing energy usage of network infrastructure, the feasibility of putting Ethernet switches hibernate or sleep mode was investigated. After that, the network topology was reorganized using clustering method based on the spectral approach for putting network switches to hibernate or switched off mode considering the time and communications among them. Experimental results show the interest in this approach in terms of energy consumption.

INTRODUCTION

We are now living in the age of information and communication technology and the energy consumption, as well as carbon emission by computing and communications equipment is increasing rapidly. Mingay (2008) stated that, at present ICT is responsible for about 2% of global carbon emissions which is similar to the aviation industry. The enhancement of energy consumption has large negative economic and environmental impact. In recent years, we are struggling with climate change and in coming years it is the greatest challenge to tackle it. For that reason, energy consumption reduction is very important because it is directly related to greenhouse gas emission which is responsible for climate change. Recent research (Pamlin and Szomollanyi, 2006) suggests that, 15-30% volume of emission needs to be decreased in order to keep the global temperature increase below 2 degree Celsius.

The growth of internet users has been astonishing over the last few years. From 1990 to 2010, the number of Internet users increased from 3 million to 2 billion and by mid-2012, the user number had increased to 2.73 billion already. Regional growth rates between 2000 and 2012 have been exceeding 3 600% in Africa and 2 600% in the Middle East. As a result, the electricity demand of ICT is growing at much faster than overall electricity demand. Network-enabled device electricity demand is growing at a rate of 6% per year and total ICT energy demand reached 1560 TWh in 2013 (Iea.org, 2014). Because of this continuous growth of internet users, the spreading of broadband access and the increasing number of online services being offered by telecoms and Internet Service Providers, the energy efficiency issue has also become one of the highest priority objectives for wired networks and service infrastructures. These continuously rising trends in network energy consumption depend on new services being offered, as well as on data traffic volume increase (Nedevschi, et al., 2008). According to Zhang, et al. (2008), data traffic is increasing rapidly which follows Moore‘s law, by doubling every 18 months.

In recent years, some efficient steps have been taken to reduce the energy consumption of network infrastructure. This paper is a contribution to this mitigation in focusing only to reduce the energy consumption of network switches in a LAN (Local Area Network). Mahadevan, et al., (2010) stated that, a network switch consumes energy during its manufacturing phase, usage phase and dismantling phase with the highest amount of energy consumed by network switch during usage phase.

The concern of this research work is only during the usage phase. The objective is to reduce the energy consumption that simple network architecture builds up with Ethernet Switches and end devices. It is described in (Iea.org, 2014), up to 80% of energy consumption is used for some devices just to maintain the network connection and more than 600 TWh of electricity was consumed on 2013 by such devices. It is possible to reduce up to 65% of energy consumption of such devices using the best available technologies and strategies. Hossain, et al., (2015) and Gunaratne, et al., (2008) found bandwidth and number of connection are mostly responsible for energy consumption of Ethernet switch in usage phase. Krommenacker, et al., (2001) and Rondeau, et al., (2001) showed proper network architecture designs and cabling plan using clustering approach increases the efficiency of the network. An efficient network design reduces traffic propagation delay, jitter, and packet loss which also reduces energy consumption. Therefore, in this paper, optimization, reorganization and clustering approach of network architecture have been proposed by analyzing bandwidth and the traffic load in point to point communication. The feasibility to hibernate or switch

off devices which only remain alive to maintain network connection was also investigated, with the objective of reducing energy consumption.

The experiment was done with cisco switches and strategies have been applied to optimize and reorganize the network topology. In the experiment, the power consumption was used to measure energy usage of network architecture. In the first phase of experiment, we designed network topology consists of connected Ethernet switches which support energywise and desktop computers were connected to each switch. Then we measured the power consumption of all switches using different bandwidth with same traffic load according to traffic matrix. In the second phase, we reorganized and optimized our network architecture using clustering method based on spectral approach, with the objective to reorganize network cabling in order to be able to sleep or hibernate unused components of network infrastructures for a certain amount of time during low traffic periods.

Hibernation mode decreases a large amount of power consumption compared to the operation mode of an Ethernet switch and switched off mode does not consume any power. In the third phase, we investigated the feasibility of putting various components connected with Ethernet switches or the switch itself to sleep or hibernate in considering the changes of communication activities. After applying the spectral approach to different cases of communication with the same network topology, it was possible to hibernate or switch off the network switch which saved a significant amount of energy.

RELATED WORK

Numerous studies have explored both in the wired and wireless network to analyze the energy consumption pattern of network devices and to reduce energy consumption using different strategies.

Related Work in Network Energy Consumption Evaluation

Christensen, et al., (2004) have studied the lifecycle energy use of network devices and explained how network devices can impact on environment pollution. The lifecycle energy use of network devices has been studied by Nordman (2008), but mostly in the context of home and office environments. Rivoire, et al., (2007) explained from a device manufacturer's point of view that, network devices such as routers and switches are power proportional which means they consume energy proportional to their usage. Gupta, et al., (2004) showed how different parameters affect the energy consumption of network switch. After that, they defined a model which shows the relationship between parameters related to the Ethernet switch and energy consumption. Fithritama, et al., (2015) proposed a method based on fuzzy logic to identify the relationships between network parameters and their effect on power consumption when deploying new network equipment. Their proposed method is also applicable to control the desired level of energy consumption by tuning the network parameters. In the research by Reviriego, et al., (2012), the energy consumption of small Energy Efficient Ethernet (EEE) switches is analyzed in several experiments. Based on the experiment result, the authors proposed a model for the energy consumption of Energy Efficient Ethernet switch.

Related Work in Network Energy Consumption Optimization

Gupta, et al., (2004) explored the feasibility of power management schemes at network switches in the LAN. They examined the possibility to put various components on LAN switches to sleep for reducing energy consumption. Experiments to evaluate energy management studies for network switches were performed by Mahadevan, et al., (2010). The authors found, energy usage in the operational stage is dominating and they parametrically examine various energy management techniques to reduce the operational energy footprint of network switches. Nedevschi, et al., (2008) presented the design and evaluation of two forms of power management schemes to reduce the energy consumption of network. They have shown that simple schemes for sleeping or rate adaptation have significant energy savings without noticeably increased packet loss and latency.

Related Work Based on Clustering Approach

Consideration of information flows is very important to design network architecture. The objective of network designer is to confine the strong co-operation and communication with sub-network to avoid flooding and overloading the whole network. In order to minimize overloading, intra-group communication should be maximum and inter-group communication should be minimum. To achieve this network scalability objective, clustering method has been widely pursued by the research community. In this research work, clustering algorithm has been used to reduce communication; isolate groups for hibernating or switched off part of the network.

Many clustering algorithms have been proposed (Abbasi, et al., 2007; Amis, et al., 2007; Baker, 1981; Bandyopadhyay, 2003; Basagni, 1999; Lin, 1997; Mellier, 2006; Chiasserini, et al., 2002) to fulfill various objectives based on wireless sensor network but none of these algorithms aim to minimize energy consumption in network architecture. Most of these algorithms are heuristic in nature and the criteria for cluster selection and node grouping are intra and inter-cluster connectivity if the application is sensitive to data latency and the length of data routing paths. The objective of these algorithms is to generate the minimum number of clusters. White, et al., (2005) proposed the spectral algorithm to find communities in a graph and showed that spectral algorithm is effective and efficient at finding both good clustering and the appropriate number of clusters from a variety of real-world graph data sets. They observed spectral algorithm is faster for large sparse graphs. Von Luxburg (2007) introduced and presented the most common spectral algorithm from scratch by different approaches. He also discussed the advantages and disadvantages of different spectral clustering algorithms, different graph Laplacians and their basic properties. Krommenacker, et al., (2001) defined some criteria to reorganize the network architecture and explored algorithms, especially the spectral algorithm to define cabling plan of switched network for real-time applications. The spectral algorithm to design the cabling plan for industrial Ethernet architecture has been used by Rondeau, et al., (2001), which can reduce handling delays of messages inside the time cycle of applications.

SYSTEM ARCHITECTURE AND CRITERIA TO REORGANIZE NETWORK SWITCHES

This section describes the general network architecture that has been used in the research and the criteria to reorganize and design efficient architecture for switched Ethernet Networks. Figure 1 shows the network architecture and the cabling plan used during the experiment. Three Cisco Ethernet Switch 2960-X (S1, S2, and S3) were used during the experiment and three desktop PCs (Personal Computer) were connected to each switch.

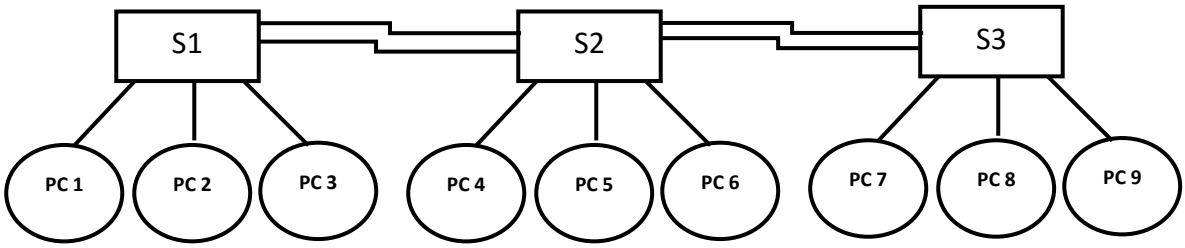


Figure 1: Cabling plan and Network architecture.

In the section below we have described the criteria to reorganize network switches in different actions.

Action 1:
It illustrates that if PC 1 has frequent communication with large data size with PC 7, then it is better to connect either PC1 in S3 or PC7 in S1. Thus, it is very important to consider information flows during designing a network. In this case, the goal is to maintain communication among devices by avoiding overloading the whole network which will increase network efficiency and reduce energy consumption.

Action 2:
The objective of action 2 is to gather the PCs strongly communicating among them, with the idea to group PCs without communication in other clusters in order to be able to hibernate or switch off these clusters.

Action 3:
If the capacity of each port of all switches is 1 Gbps and total traffic load for the communication between S1 and S2 or S2 and S3 are more than 1Gbps, then more than one trunk port needs to be connected to support the communication. In this situation, if inter-switch communication can be reduced, it is possible to eliminate redundant trunk between two switches. Thus reducing the traffic between switches allows reducing bandwidth and as a result, reduction of energy consumption.

Therefore, in general, the criteria to reorganize the communication among switches are to minimize inter-group dialogues in order to maximize the intra-group exchanges or to create groups without communication. Some other criteria should also take into account such as the number of ports and capacity of each port with the objective to use the smaller number of switches with a higher number of connected ports.

METHODOLOGY

The spectral algorithm is used to cluster the end device according to the usage of switch ports and to ensure the minimal interaction between two clusters. As an initial step of the approach, a graph G_d has been introduced and translated that into traffic matrix according to the communication among end devices.

This section describes clustering method based on the spectral approach which has been used to reorganize and optimize network topology.

Spectral Approach

The spectral algorithm is one of the most successful heuristics for partitioning graphs and matrices. This approach is used to solve scientific numerical problems such as solving parse linear systems explained by Pothen, et al., (1992), partitioning for domain decomposition (Chan and Smith, 1994), Ethernet architecture segmentation (Rondeau, et al., 2001) and so on. In this research spectral approach has been used to

- Adjust the size of the clusters in regard to the capacity of the switches in terms of port number.
- Reorganize and minimize the cabling of the switch by breaking graphs into sub graphs.
- Investigate the feasibility of putting unused switches to hibernate or switched off according to usage.

Given an undirected weighted graph $G = (V, E)$, where G is a division of its vertices v into two disjoint subsets, V_1 and V_2. Let $E(V_1, V_2)$ is the set of edges (links for communication) e_{ij} with one endpoint in $V_1$and other in V_2. The cut size of the partition is the sum of the edge weights of of E :

$$c = \sum_{eij \in E} w(eij)$$

Where $v_i \in V_1$ and $v_j \in V_2$

Here the objective is to find a disjoint subset of $V, P = \{v_i\}$ which minimizes c .
The adjacency matrix $A(G_d)$, of the graph G is $n \times n$ matrix where (ij)th entry is the weight of edge e_{ij} : w_{ij} and 0 otherwise. For adjacency matrix, the diagonal entries are always 0.

As the spectral algorithm considers only undirected graph, thus it needs to work with
$A(G) = A(G_d) + A(G_d)^t$

Algorithm Description

Let D (G) is an undirected graph converted into $n \times n$ diagonal matrix such as

$$d_{ii} = \sum_{j} w(eij)$$

The Laplacian matrix $L(G)$of the graph G is $L(G) = D(G)$ - $A(G)$.
According to (Donath, et al., 1973; Fiedler, 1973, 1975a, 1975b) a good cut size is the second smallest eigenvalue λ2 and its associated eigenvector $\vec{u}$ = $(u_1, u_2, \ldots\ldots u_n)$ (Fiedler vector).

Now, sorting the vertices on the incremental way according to the values of the components of Fiedler vector gives the reorganization of the vertices.

The objective of the partitioning is to use exactly d devices (in this case network switches) and to minimize the communication through the switches if there are two levels of switches. A splitting value s should be found for spectral partitioning which divides the vertices of G into V_1 such that $u_i > s$, and V_2 such that $u_i < s$ and that is called a Fiedler cut. The choices for the splitting values s are:

- Bisection cut, where s is the median of$(u_1, u_2, \ldots\ldots\ldots\ldots u_n)$.
- Sign cut, where s is equal to 0.
- Ratio cut, where s is the value that gives the best cut ratio denoted $\emptyset$ with $\emptyset(V_1, V_2) = |E(V_1, V_2)|/\min(|V_1|, |V_2|)$
- Gap cut, where s is the value in the largest gap in the sorted list of the Fielder vector components.

To partition a graph into the power of two numbers of groups, Recursive Spectral Bisection (RSB) algorithm explained by Simon (1991) is applied. In this paper, optimized recursive bisection algorithm has been used for partitioning the graph.

Optimized Recursive Spectral Bisection Algorithm (RSB in $[\mathbf{d}/2]$)

Simon (1991) proposed improvement on RSB algorithm for designing a switched Ethernet network cabling plan as follows:

1. Compute the Fiedler vector for the graph.
2. Sort the vertices according to the values of the components of the Fielder vector.
3. Calculate d for the group to be partitioned.
4. Assign $n[d/2]$ first vertices to one sub-group and the others to the second one.
   Cut of value ($n[d/2]$) = $\text{number of ports} * [\text{number of devices}/2]$.
5. Apply steps 1-4 recursively to each sub-group until the size of each sub-group becomes$\leq n$.

RESEARCH METHOD AND EXPERIMENT DETAILS

Parameter Selection

Parameter selection is one of the most important issues for power management of Ethernet switch. Bandwidth and the number of connections are mostly responsible for energy consumption of Ethernet switch (Hossain, et al., 2015) and the packet size has no impact on energy consumption of the switch (Mahadevan, et al., 2009).So in our experiment bandwidth, the traffic load on each switch port and traffic matrix according to the communication among end devices was used as the input parameter and power consumption of switch was measured as the output parameter. Though traffic load has very little impact on energy usage, but it represents the service that the network must offer (QoS). In the experiment traffic load was used to maintain the frequency of communication among the end devices and to draw traffic matrix depending on that communication.

Detailed Experiment

The experiment was done according to the figure 1. Powerspy2 sensor was used to measure the total energy consumption of three switches which can send real-time energy consumption data via

Bluetooth (Hossain, et al., 2015 and PowerSpy2 user manual, 2015). Ostinato traffic generator was used to generate traffic into the switch ports (Ostinato Network Traffic generator and Analyzar User Guide). Three sets of experiment were done and each set contains two experiments. During each set of experiment, for all switch ports, the same bandwidth was used which were 100Mbps and 1Gbps. Depending on the traffic load and frequency of communication we have designed 9×9 traffic matrix and measured energy consumption of the network topology. According to the frequency of communication among end devices, two types of traffic loads has been used which are defined as large transmission and small transmission which are shown in traffic matrix as "10" and "1" in respectively. More information about traffic loads and frequency of communication is shown in Table 1. Each experiment was run and monitored for 15 minutes.

	For large transmission (10)	**For small transmission (1)**
Frame size (Byte) :	1125	1125
Packet per second:	10000	1000
Total size of transmission per second (Mbps)	90	9

Table 1: Traffic load and frequency of communication.

RESULTS AND DISCUSSIONS

This section presents the obtained result during the test phase. In traffic matrix, the red marked PCs are connected with S1, blue marked PCs are connected with S2 and green marked PCs are connected with S3.

Case Study

For conducting the experiment, communication among the end devices during day time or working hours and night time or nonworking hours was considered. The working hour was defined as $\mathrm{T}_1 = 16\ \mathrm{hours}$ and the nonworking hour was defined as $\mathrm{T}_2 = 8\ \mathrm{hours}$. The communication among the end devices is more than nonworking hours which have been shown by traffic matrix1 and matrix2 accordingly in Figure 7. Both of the matrices in Figure 7 are unoptimized.

The architecture is composed of 9 PCs connected to 3 Ethernet switches (respectively S1, S2, and S3) with the capacity of five ports each switch as explained in figure 1. Figure 7 shows that PCs in red (1, 2 and 3) are connected to switch S1, PCs in blue (4, 5 and 6) to switch S2 and PCs in green (7, 8 and 9) to switch S3.

Matrix 1

PC No	1	2	3	4	5	6	7	8	9
1				10				10	1
2					10				10
3						10	10		
4	10							10	
5		10				1		1	10
6		1	10				10		
7			10			10		1	
8	10			10			1		
9		10			10				

T_1

Matrix 2

PC No	1	2	3	4	5	6	7	8	9
1									
2					10				10
3									
4									
5		10							10
6									
7									
8									
9		10			10				

T_2

Figure 7: Traffic matrix according to the communication among end devices during working and non-working hours.

In this case, most of the frequent communications are intra-switch communication and in optimized organization, most of the frequent communications are inter-switch communication among end devices showed in Figure 7. The total amount of traffic load is same for both matrices.
The yearly power consumption for Figure 7 can be calculated by the formula below:

$$P_{total} = (T_1 P_{matrix1} + T_2 P_{matrix2}) * 365$$

Here P_{total} is the yearly power consumption, $T_1 P_{matrix1}$ is daily power consumption for Matrix 1 and $T_2 P_{matrix2}$ is daily power consumption for Matrix 2.

Table 2 and Table 3 shows the experimental results of power consumed by the network architecture showed in Figure 1 for 100 Mbps and 1Gbps bandwidth. For all measurements, bandwidth for both trunk ports and the ports connected to end devices was same and two trunk ports were connected between each switch to support communications.

Time	Working hours (T_1)	Non-working hours (T_2)	Total
Power consumption (KWh/Year)	598.6	299.6	898.2

Table 2: Power consumption for 100 Mbps bandwidth in the unoptimized organization.

Time	Working hours (T_1)	Non-working hours (T_2)	Total
Power consumption (KWh/Year)	620.8	308.9	929.7

Table 3: Power consumption for 1 Gbps bandwidth in the unoptimized organization.

There is no notable change in power consumption for traffic load, but there is a noticeable change in power consumption when there is a change in bandwidth. The power consumption increases 0.2 to 0.4 Watt per port if the link speed is changed from 100 Mbps to 1Gbps respectively. Reducing bandwidth from 1 Gbps to 100 Mbps could save yearly 33.3 KWh in the unoptimized organization where 5 ports in each switch were active. Another noticeable observation is, an extra trunk link was

needed in working hours for the unoptimized organization to support communication and to avoid packet loss for traffic overload between S1 and S2.

For clustering and optimizing the communication and cabling plan for the whole day, the weights of Matrix 1 and Matrix 2 have been calculated considering the time T_1 and T_2 respectively and the spectral algorithm was implemented on that matrix. It has been assumed that Matrix 1 and Matrix 2 are derived from connected graph G1 and G2 respectively. The weight of G1 and G2 is defined by C which is shown in Figure 8.

PC No	1	2	3	4	5	6	7	8	9
1				160				160	16
2					240				240
3						160	160		
4	160							160	
5		240				16		16	240
6		16	160				160		
7			160			160		16	
8	160			160			16		
9		240			240				

$C = T_1G1 + T_2G2$

PC No	1	2	3	4	5	6	7	8	9
1				320				320	16
2					480	16			480
3						320	320		
4	320							320	
5		480				16		16	480
6		16	320		16		320		
7			320			320		32	
8	320			320	16		32		
9	16	480			480				

A(C)

Figure 8: Combined matrix and undirected adjacency matrix for the communication.

As the spectral algorithm works with only undirected graph, so A (C) = C+C' has been calculated shown in Figure 8 and from there Laplacian matrix L(C) has been calculated which is shown in Figure 9.

0.45919	3
-0.12275	6
-0.34744	7
0.46906	2
-0.11657	5
-0.33986	9

L (C)
Vertices

5	6	7	8	9
			−320	−16
−480	−16			−480
	−320	−320		
			−320	
992	−16		−16	−480
−16	672	−320		
	−320	672	−32	
−16		−32	688	
−480				976

$V_{FIEDLER}$ Sorted

Figure 9: Laplacian matrix for graph C

Figure 10: Fiedler values and sorted vertices for the Graph G.

After computing the Fielder vector for the graph C and sorting the vertices according to the values of the components of the Fielder vector, sorted vertices showed in Figure 10 were obtained.

Here nine end devices are connected to three network switches with the capacity of five ports where two ports are connected as trunk. The sorted vertices from Figure 10 have been used as end devices. After applying improvement on RSB algorithm (Rondeau, et al., 2001), the obtained result of Figure 11 partitioned the end devices into three parts and the group of three end devices is connected to each switch.

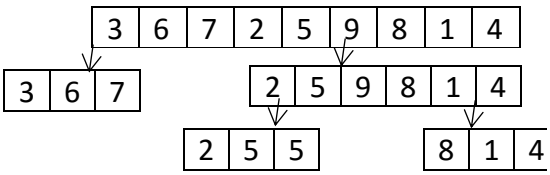
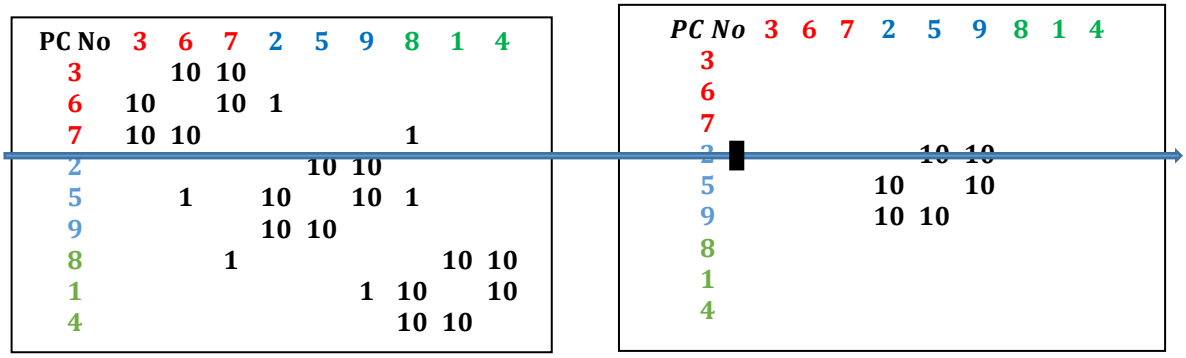


Figure 11: Partitioning of End Devices by Using RSB in $n[d/2]$

The optimized adjacency matrix was drawn based on working hours and nonworking hours according to the serialization found in Figure 12.



T_1
Optimized Matrix 1

T_2
Optimized Matrix 2

Figure 12: Optimized Matrix 1 and Matrix 2.

The power consumption by the optimized solution is measured which is showed in Table 4.

Table 4: Power consumption for working hour and nonworking hours for optimized solution.

Power Consumption at Working hours (T1) by Optimized Organization		
Bandwidth	**100 Mbps**	**1 Gbps**
Energy consumption (KWh/Year)	596.3	613.8

Power Consumption at Nonworking hours (T2) by Optimized Organization (KWh/year)			
Bandwidth	**With Trafic**	**Hibernate**	**Switched off**
100 Mbps	298.7	218.1	99.9
1 Gbps	306.9	219.6	100.7

Table 5: Total yearly power consumption for the optimized solution for different bandwidth.

	Power consumption for 100Mbps bandwidth (KWh/year)	Power consumption for 1Gbps bandwidth (KWh/year)
Always active	895.0	920.7
With hibernation	814.4	833.4
With Switched off	596.1	613.8

Table 5 shows the yearly total power consumption of optimized solution using the spectral algorithm. The result shows that optimized solution consumes less energy than unoptimized architecture. It was also possible to reduce extra trunk port between S1 and S2 during working hours because spectral algorithm produced clusters of PCs which have strong communications among those which reduce inter-switch communication showed in optimized Matrix 1. After applying spectral clustering on end devices and serialization of network switches, it was possible to hibernate or switch off two network switches (S1 and S3) during nonworking hours because it created two clusters of PCs without communication which are connected with S1 and S3.

Table 6: Power saving by using optimized solution

	Power saving for 100Mbps bandwidth (KWh/year)	Power Saving for 1Gbps bandwidth (KWh/year)
Always active	3.2	9.0
With hibernation	83.8	96.3
With Switched off	202.1	315.9

Table 6 shows the power savings after using the spectral algorithm for different bandwidth. For 100 Mbps bandwidth, the optimized solution could save a yearly minimum of 3.2 KWh when no hibernate or switched off feature activated to maximum 202.1 KWh with switched off feature activated during nonworking hours. For 1Gbps bandwidth, the optimized solution could save 9.0 KWh when no hibernate or switched off feature activated to maximum 315.9 KWh for switched off feature activated during nonworking hours.

For hibernation or switched off Ethernet switch, it should be considered the Quality of Service. The hibernation mode consumes about 20 watts and switched off mode consumes nothing. For the Cisco switch model 2960-X, it takes 260 seconds to get ready after wake up from hibernation and 290 seconds from switched off mode. The time difference to be fully functional from hibernation and switched off mode is 30 seconds which can be critical for few cases. But for normal office works or Local Area Network, it doesn't have that much impact. Frequent on-off can put extra load which can reduce lifetime and some devices are vulnerable to this situation. On the other hand, always keeping on a device can also reduce lifetime, therefore switched off can be a good choice too. Hibernation and wake up time can be scheduled by command line which is not possible for switched off mode but by using rack power distribution units (PDUs) it is also possible to switch off and on automatically. Therefore, the choice of hibernation or switched off Ethernet switch can be according to the necessity of the user.

The spectral approach is also applicable for optimizing bigger network architecture. So by using clustering method based on spectral approach, it is possible to save a large amount of energy according to traffic loads and pattern for the bigger picture and more complex architecture. The Ethernet switch is only a part of network architecture and to put efficient and greater impact, other

network components like router, WIFI hotspot etc. should be considered. It is also possible to apply the spectral algorithm for clustering those devices according to traffic and optimize the whole architecture. Moreover, the experiment was done with one type of Ethernet switch, so the result may vary for different type of switches. Rondeau, et al., (2015) mentioned the correlation between the power consumption and carbon emission. Therefore, by optimizing network architecture using the spectral algorithm, it is also possible to reduce carbon footprint caused by network equipment. As a big picture, with proper design and development of network architecture, it is possible to reduce and control global energy usage and carbon footprint caused by network devices.

CONCLUSION

The enhancement of energy consumption by network infrastructures has large negative impact on sustainability which should be controlled. This paper presents a novel way of energy efficient network design and management system by using the clustering approach based on spectral algorithm to reduce energy consumption of network infrastructure. By using this approach, it is possible to hibernate or switch off part of network during low traffic hours in order to save energy. Experimental result shows that significant amount of energy can be saved by reorganizing the network switches and clustering the end devices using the spectral algorithm. For future work, this approach can be applied to the bigger network architecture and big enterprise which has the potential to save a large amount of energy usage. Similar experiments can be done for other network devices such as routers to reduce more energy consumption.

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Energy, Recycling, Materials and Waste

PRODUCTION OF CLAY COATED LIGHTWEIGHT FILL MATERIALS FROM AIR POLLUTION CONTROL RESIDUES (APCR)

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Keywords: Air pollution control residues, Clay coating, leaching and Recycling.

ABSTRACT

Air pollution control residues (APCr) from energy-from-waste are classified as hazardous due to their high heavy metal content and alkalinity. Recycling attempts using thermal treatment to produce a ceramic material known as lightweight aggregate have been successful in incorporating a maximum of 10% of APCr in the final product's structure. The aim of this work was to increase this incorporation by producing macro-encapsulated APCr granules with a clay coating. APCr has been washed with deionized water, milled and mixed with different concentrations of sodium silicate to form into granules. Sodium silicate solution was added to the mix to enhance the content of silicate and flux. The green pellets were coated with clay and sintered in a laboratory furnace at 1150 °C. The effect of addition of sodium silicate on particle density, water absorption and compressive strength has been discussed. Leaching behaviour of heavy metals and soluble anions from the sintered granule was examined according to BS EN 12457. Optical micrographs of the sintered products were investigated to reveal the microstructure of the binding interface between APCr and clay coating. The results showed that incorporation of up to 30% of APCr in the structure of sintered granules is possible. The proposed clay coating technique is simple and can reduce the leaching behaviour of hazardous waste.

1 INTRODUCTION

During the waste incineration process, the generated exhaust gases must undergo a treatment through which the contaminants within the gases are separated in a solid filtrate, known as air pollution control residues (APCr). They are classified as a hazardous waste due to high levels of soluble chlorides, sulphate salts and lead, and are usually disposed of in special landfills (Amutha Rani et al., 2008a). Approximately, 200,000 tonnes of APCr is produced in the UK annually, a number which is expected to increase due to the UK's growing incineration capacity (Astrup, 2008).

Current disposal, treatment and management options for APCr, alongside a number of alternative recycling technologies, are summarized in Table 1. APCr with the current compositions cannot meet the waste acceptance criteria set by the EU for hazardous landfills (Quina et al., 2008b). In addition, traditional treatments such as solidification with a binder have been associated with a significant increase in the volume of waste and long-term instability due to the high salt content of residues (Quina et al., 2008a). Carbonation has been shown to be only able to temporarily stabilize the material before final disposal (Zhang et al., 2008). Other chemical stabilization methods using caustic solutions such as soluble sodium silicate, ortho-phosphoric acid and sodium carbonate are reported to have a positive effect on leaching of Pb and Zn but still problematic in case of chlorides, implying the need for a washing stage (Quina et al., 2010, Shirley and Black, 2011).

Table 1, Current options in the UK's to deal with APCr, taken from (Amutha Rani et al., 2008a).

Disposal/treatment options	Treatment technologies	Thermal treatment
• Disposal to hazardous waste landfill • Storage in deep salt mines • waste acid treatment	• washing • Chemical stabilisation processes • Solidification	• Vitrification • Melting • Sintering

Thermal treatments such as vitrification, melting and sintering are employed for producing environmentally stable glass-ceramic products (Trujillo-vazquez et al., 2009, Roether et al., 2010). In thermal vitrification process, silica and alumina are added to APCr and the mix is melted under reducing conditions using DC plasma arc technology. This technique has been shown to be effective in encapsulating the volatile heavy metals and soluble salts into an amorphous matrix, and also in preventing the generation of NO_x and HCl due to the presence of an inert argon atmosphere (Amutha Rani et al., 2008b). However, the main drawback of the plasma technology is the high cost that is required for the input power (Quina et al., 2008a). Studies on producing lightweight aggregate from APCr and clay have been successful to incorporate a maximum of 10% of washed APCr in the structure of products however, the technical advantage of this method is still in doubt (Quina et al., 2014a, Quina et al., 2014b). This work aimed at producing clay-coated APCr granules by using thermal treatment. The objective was to employ a combination of methods such as washing, chemical and physical stabilization and sintering to obtain optimal mechanical properties and minimal leaching of contaminant.

EXPERIMENTAL

Materials

APCr samples were collected from one the UK's energy from waste (EFW) plants. The clay was taken from an excavated clay recycling plant in East London. Sodium silicate solution (AVONCHEM, UK) with a module of approximately 3.2 was used as a sintering promoter. APCr were characterised for total metals, pH and alkaline reserve, total chloride and total dissolvable solids (TDS). APCr were washed with 10 times of distilled water (L/S=10) for 1 hour, vacuum filtered and dried at 105 °C until they reach a constant weight.

Manufacture of granules

A washed sample of APCr was milled in a planetary ball mill at 300 rpm to reach a maximum particle size of 125 µm. The milled sample was then mixed with sodium silicate at concentrations ranging from 20% to 50% with 10% increments and to form into wet 'green' granules (water was added in this stage to help the granulation). The 'green' granules were dipped in dried clay with particle size <125 µm in a rotational custom made drum granulator (diameter: 350 mm, rotational speed: 100 rpm). The batch was processed for 10 minutes to allow a clay-coating to be deposited on the wet surface of APCr/sodium silicate granules. The granules were checked during the process to control the coating thickness. When the coating reached 1±0.3 mm, the process was terminated. The coated granules with particle size ranging from 3mm to 6mm were dried at 105 °C for 2 hours and fired at 1150 °C for 20 minutes in a muffle furnace.

Characterization of sintered granules

Density, water absorption capacity and compressive strength of the sintered clay coated granules were evaluated as three main indications of final products' mechanical properties, using following formulas:

Particle density (ρ_{dr}) (specific gravity) and water absorption (WA) were calculated according to BS EN 1097-6:2000 Where, M_1 is the mass of the saturated surface-dried granules (24 h in water and dried in air); M_{im} is the apparent mass (immersed mass); and M_d is the mass of oven-dried granules.

$$\rho_{dr} = (\rho_w \times M_d) / (M_{ssd} - M_{im})$$

$$WA = 100 \times (M_{ssd} - M_d) / M_d$$

Compressive strength was calculated by loading the granules to fracture between two parallel rigid surfaces and using the following equation (Cheeseman et al., 2005):

$$S = (2.8Pc) / (\pi X^2)$$

Pc is the fracture load (N) and X is the distance (mm) between the loading points. A testing apparatus with a 4.55 kN capacity load-ring was used. Figure 1 shows the position of an individual granule under the load. The movement of the upper plate was adjusted at 0.5 mm/min.

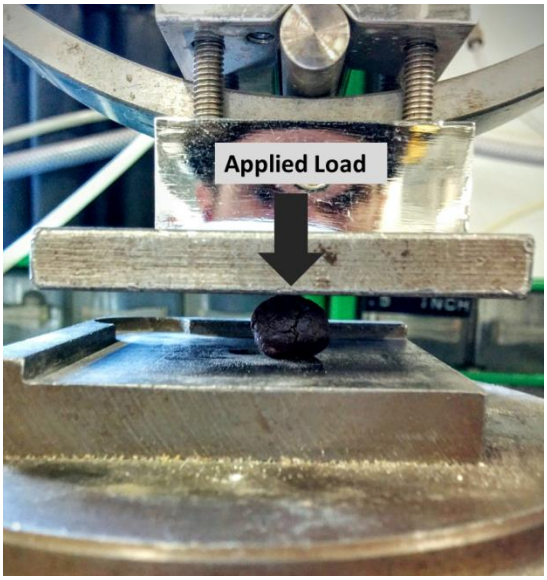


Figure 11. Position of a granule under the applied compressive load.

For microstructural characterization, a Keyence corporation (Japan) VHX-2000 optical microscope with lenses VH-Z20R/W and VH-Z500R/W was used.

Leaching analysis was performed according the European standard EN 12457. For the test, the granules were leached in deionised water at a liquid to solid ratio (L/S) of 10 l/kg under constant rotation for 24 h. The test was carried out at the materials own pH. The resulted leachate was then filtered and the concentrations of inorganic constituents were measured by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The limit values established in European Landfill Directive (2003/33/EC) were used as a reference criteria to compare the measured concentrations (Rocca et al., 2012).

RESULTS AND DISCUSSIONS

Characterization of APCr and clay

Properties of the APCr sample including pH, alkali reserve, total metals and chloride content together with the results of leaching test (BS EN 12457-2) and waste acceptance criteria (WAC) limits for hazardous landfills are shown in table 2. Among metals, leaching of lead was extremely high (723 mg/kg) which was expected due to its high total concentration (1,840 mg/kg) in as-received APCr sample. In addition, high levels of chloride, total dissolved solids (TDS) and dissolved organic carbon (DOC) exceeded the acceptance criteria for hazardous landfill.

Table 2, Bulk chemical compositions of the APCr sample and the results of BS 12457-2 leaching test compared with limits for hazardous waste.

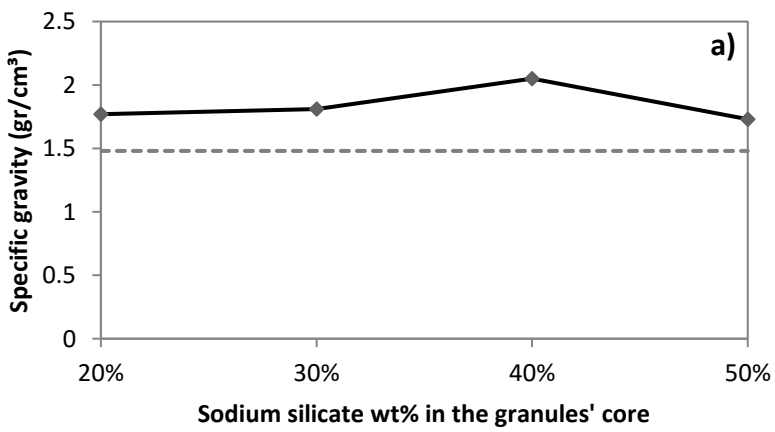
Total metals mg/kg		BS 12457-2 LS = 10 (mg/kg)		Hazardous Limits as expressed in landfill directive mg/kg
As	<3.82	As	<1.46	25
Ba	429	Ba	126	300
Cd	116	Cd	<0.081	5
Cr	114	Cr	5.24	70
Cu	611	Cu	14.2	100
Pb	1,840	Hg	<0.353	2
Hg	<0.92	Mo	2.03	30
Mo	11	Ni	0.13	40
Ni	41	Pb	723	50
Sb	543	Sb	<1.383	5
Se	<1.67	Se	<0.664	7
Zn	9,190	Zn	168	20
pH	12.68	Cl	199000	25000
Alkali Reserve	20.96	F	37.7	500
Ca	303,000	SO4	13600	50000
K	39,300	TDS	353000	100000
Na	37,800	DOC	162	100
Cl	199,000			

Sintered granules

Figure 2a – 2d show granules with a sintered clay coating and a bright APCr core containing 20, 30, 40 and 50 wt% sodium silicate. The sintered granules with 20% sodium silicate were weak and chalky with a fractured coating. Coating fractures in Figure 2a and Figure 2b also suggest shrinkage in the coating during the firing process. Adding 40% of sodium silicate to the core could act as a sintering promoter and affect the clay particles to bind in a liquid phase. The optimum concentration of sodium silicate in the core was found to be 40% which could produce regular granules with minimal coating fractures. 50% addition of sodium silicate was detrimental as it caused agglomeration and excessive melting of both core and coating.

Figure 2. Granules with a sintered clay coating and APCr core containing: a) 20%, b) 30%, c) 40% and d) 50% sodium silicate.

Figure 3 shows the effect of sodium silicate addition on density (specific gravity), water absorption capacity and compressive strength of the sintered granules. The dashed line represents the mechanical properties of a commercially available lightweight aggregate called Lytag (Cheeseman et al., 2005). Sodium silicate addition up to 40% increased the mean density to 2 gr/cm^3. Above that concentration the mean density decreased to 1.73 gr/cm^3. Water absorption significantly decreased with sodium silicate addition and reached below the Lytag's capacity for granules with a core containing 30% sodium silicate. The highest compressive strength, 3.3 MPa, was achieved with 40% sodium silicate. The observed trends in water absorption and compressive strength with addition of sodium silicate, are possibly due to the fluxing effect of sodium silicate which would promote the liquid phase sintering and thus, improve the ceramic properties of both core and coating (Bourtsalas et al., 2015). The presence of liquid phase sintering was investigated by analysing the microstructure of the sintered granules with a core with 40% sodium silicate, using an optical microscope. For this batch of granules, the amount of incorporated APCr was estimated between 25 to 30%.



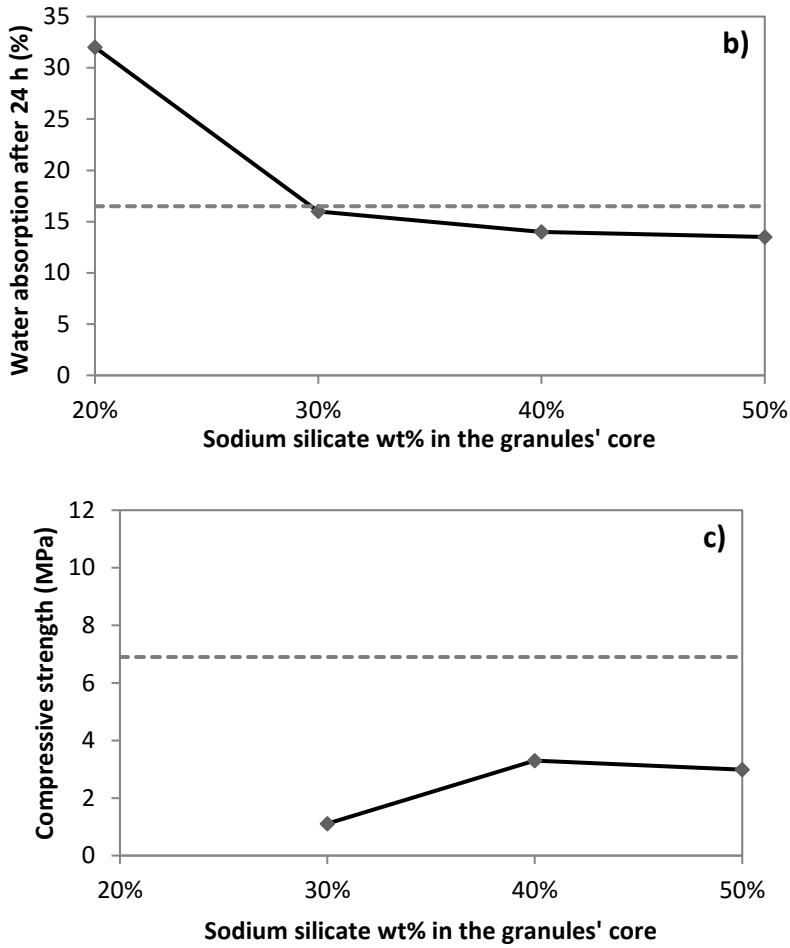


Figure 3. Effect of addition of sodium silicate to the APCr mix on the mechanical properties of the sintered granules: a) specific gravity, b) water absorption after 24 hours, and c) compressive strength of individual pellets. The dashed line shows approximate values for Lytag.

Figure 4 shows optical micrographs of the sintered granules structure with 40% sodium silicate. The clay coating was polished to access the APCr core (Figure 4a). This revealed a number of layers and microstructural features that had been generated during the firing process. Figure 4b shows an image of the clay coating surface. Presence of a vitrified glassy layer on the surface of the clay coating was detected in most areas. It must be noted that this glassy layer was non-porous and crack-free which could have affected the possible leaching of contaminants. Figure 4c shows three distinctive layers and their thicknesses measured at different spots. First, a sintered clay layer with a thickness between 400µm and 500µm measured at three spots numbered as 1, 4 and 7. Second, a bloated layer measured at 2, 5 and 8 composed of bubbles with various sizes. Third, an intermediate densified silicate based layer with a thickness up to 680µm measured at 3, 6 and 9.

Figure 4e – 4g show magnified images of each distinctive layer. A semi-crystalline structure for the clay coating can be seen in Figure 4e. In addition, the formation of a densified layer at the vicinity of clay (Figure 4g) was possibly due to the accumulation of silicates (dissolved in water). Dry clay particles as they attach to the wet surface of the APCr granules (during the coating process) may have absorbed the silicate solution towards the surface of the core and facilitate the formation of an adjacent silicate based layer. The bloating effect, shown in Figure 4f, can be explained through similar

reactions that happen during the production of lightweight aggregate (de' Gennaro et al., 2004). Here, the fluxing capability of the absorbed sodium silicate into clay, has resulted in phases with lower melting points which enveloped any released gaseous phase at that temperature (Riley, 1951).

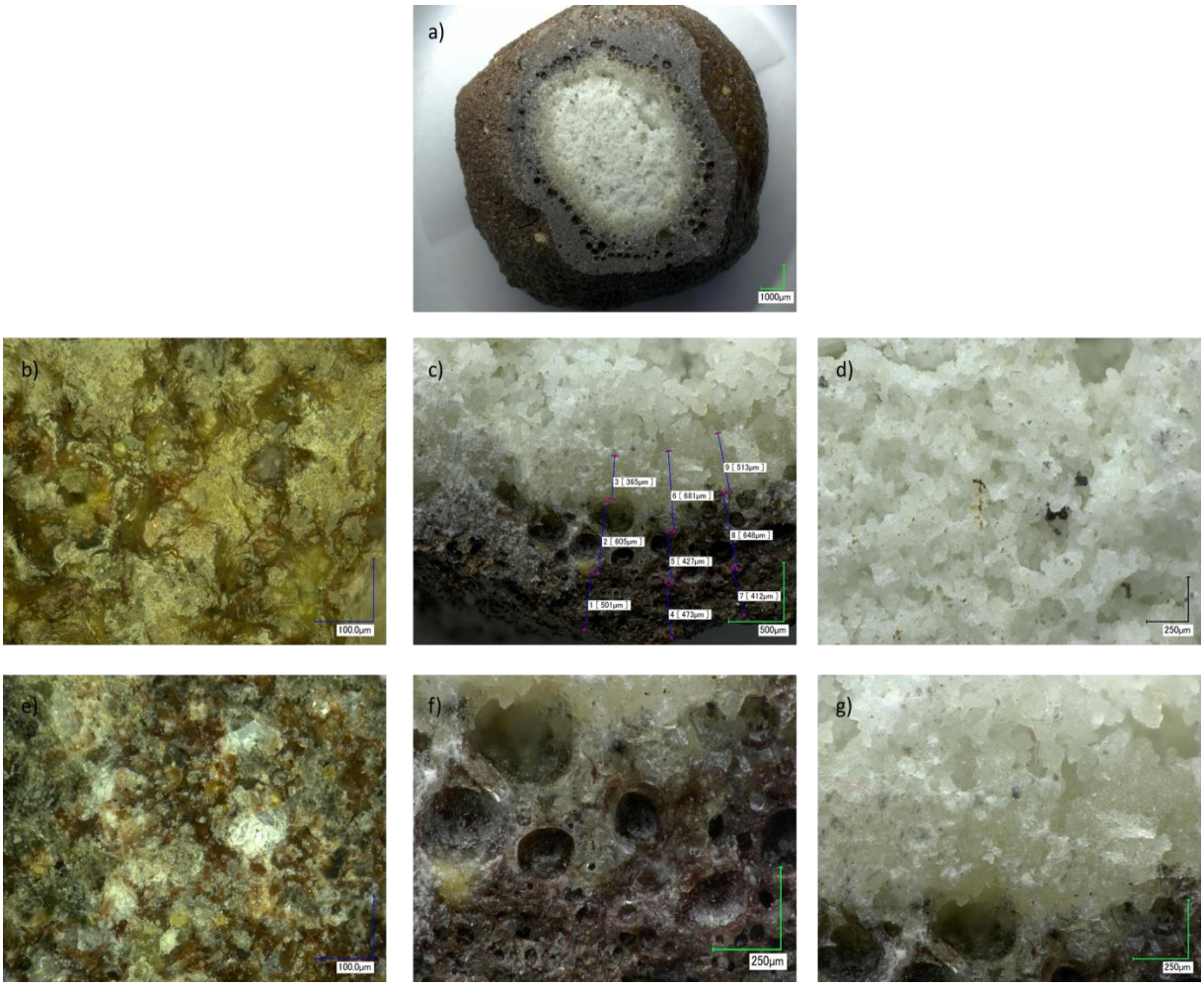


Figure 4. Optical micrographs of the sintered granules with 40% sodium silicate: a) polished granules revealing the core and the clay coating, b) vitrified and non-porous surface of the clay coating, c) thickness measurements of the layered structure, d) grains of APCr and sodium silicate with some inclusions, e) sintered semi-crystalline clay coating, f) bloating effect, and g) a densified silicate based intermediate layer.

Table 3 shows the results of BS EN 12457-2 leaching test and limit values in the EU landfill directive for hazardous, non-hazardous and inert waste. Comparing with leaching test results of untreated APCr (shown in table 2) it is evident that the leachate's concentrations in all cases have decreased to a large extent. For example, leaching of Pb, Zn and Cl which had exceeded the limits for hazardous waste, reached below the limit values for inert waste after the thermal treatment. However, despite passing the criteria for hazardous and non-hazardous waste, the manufactured granules could not be classified as inert since levels of Cr, F, SO_4 and total dissolved solids were still slightly higher than the specified limit values. Leaching of these constituents could be originated both from the APCr internal structure (granule's core) and the clay coating which was in contact with the water for a long time during the leaching test. It is more likely that the contaminants have leached out through capillary pores within the coating. These pores may have remained in the structure of the coating as

a result of incomplete sintering or lack of surface verification. Here, it must be noted that the initial washing stage had already reduced the concentration of Cl in APCr and its low concentration in the leachate is mainly due to the fact that Cl compounds are very soluble and solubilise rapidly while other anions such as sulphate remain within the material during a short washing stage (Chimenos et al., 2005, Lampris et al., 2008). To solve the leaching problem, more control over the firing process and possibly use of a rotary kiln are suggested.

Table 3, BS 12457-2 leaching test results and concentration limits (as expressed in the EU landfill directive 2003/33/EC) for landfill for hazardous, non-hazardous and inert waste.

Constituents	BS 12457-2 LS = 10 (mg/kg)	Hazardous Limits As expressed in landfill directive (mg/kg)	Non-Hazardous Limits As expressed in landfill directive (mg/kg)	Inert Limits As expressed in landfill directive (mg/kg)
As	<1.460	25	2	0.5
Ba	1.4	300	100	20
Cd	<0.081	5	1	0.04
Cr	0.7	70	10	0.5
Cu	<0.356	100	50	2
Hg	<0.353	2	0.2	0.01
Mo	<0.819	30	10	0.5
Ni	<0.104	40	10	0.4
Pb	0.3	50	10	0.5
Sb	<1.383	5	0.7	0.06
Se	<0.664	7	0.5	0.1
Zn	<3.095	20	50	4
Cl	<51.0	25000	15000	800
F	<20.3	500	150	10
SO4	1994.4	50000	20000	1000
TDS	4300	100000	60000	4000
DOC	<300.00	100	800	500

CONCLUSION

This work proposed a simple and effective technique for recycling of APCr which is one of the most problematic hazardous waste. It was demonstrated that mixing APCr with sodium silicate for granulation and applying a clay coating through thermal treatment can result in a product with suitable mechanical properties which could incorporate up to 30% APCr in its structure. The addition of sodium silicate was beneficial in reducing the overall sintering temperature and promoted the liquid phase sintering which improved the strength of the granules. Optical micrographs revealed the presence of three distinctive layers in the structure of granules including: a sintered clay based coating outer layer, a bloated intermediate layer and a densified silicate rich surrounding the internal core. Leaching of the contaminants was significantly decreased below the EU limit values for hazardous and non-hazardous waste. The study showed that a clay coating may have the potential for recycling APCr into an inert fill material that can be utilised for civil engineering applications.

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Life Cycle Analysis

THE DEVELOPMENT OF BUILDING EVALUATION METHODOLOGIES: FORGOTTEN IDEAS AND THE STATE OF THE ART

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Keywords: Environmental design, Post-Occupancy Evaluation, Building Performance Evaluation.

ABSTRACT

For a long time, sustainable design of buildings has focused on reducing energy consumption. This has taken architectural design away from understanding the wider variety of factors that affect the building during its lifetime.

This paper summarizes the findings of the most influential Post-Occupancy Evaluation methods that have been published during the past 60 years. It aims to monitor the changes that have occurred to the methodology, and create an understanding of the different issues they have explored. Current building evaluation methods are not widely applied due to barriers that originate to reasons that are no longer applicable. UK building legislation recommends Post-Occupancy Evaluations in buildings, but seems unable to demand it. Contemporary evaluation methods offer benefits, but fail to create a framework that would follow the building throughout its life cycle, as they are investigating a limited amount of factors that affect its performance. There is a need for a more generalised approach to building design that would take into consideration factors like occupant opinion, architectural design together with energy consumption. The Soft Landings framework offers a simple and easy to use method, but is designed for non-domestic buildings.

The paper proposes the research of a variation to the Soft Landings framework, appropriate for domestic buildings, which constitute a large fraction of the built environment. This method would aim to include the users in the design process, educate and inspire them about the efficient use of their home, throughout its lifetime.

INTRODUCTION

For more than half a century, there has been a growing need to obtain feedback from buildings. Since the early examples of post-occupancy research in buildings (Manning, P. N. et al., 1965; Ryn, Van der et al., 1967; Markus et al., 1972), designers and researchers have constantly aimed to understand the factors that affect the building during its lifetime. Different occupants, variation of needs, changes of use, maintenance, and technological advancements are among the issues that have been spotted to mainly affect the buildings. Inclusive tables of these factors have been published for a variety of building types that were examined during the 1970s (Friedmann et al., 1978).

Understanding the importance of the users and their influence on each building should be an integral part of the design process; a process that should not stop on the sign-off of the building to the client, but continue throughout its life time. Especially in the domestic sector, building performance depends on use. As the user and their needs evolve through time (number of occupants, user occupation, climate change, etc.), it is imperative that the building design and services should evolve accordingly. Depending on the retrofit requirements, any changes, from minor design issues to major retrofit, need to be carried out by experts in each respective field, according to trade regulations.

This paper aims to present the results of the literature review that the author currently undertakes in order to create a firm theoretical substrate for his Ph.D. research that is currently under way. This review would substantiate the research questions and assist the decision for the work that needs to be conducted for the purposes of the Ph.D.

Building evaluation tools and methodologies throughout history

The value of obtaining feedback and evaluating a building's design has been presented very clearly throughout literature and many professions constantly use feedback methods to push their products forward. Bartholomew describes the process of learning through observation and questioning of the environment even from our infancy. The collection of information and data is crucially important and today's technology assists in the collection of data at a very large scale. He adapts this process to the construction sector and collects expertise and opinions from a number of important players that cover a large spectrum of specialization. He describes the methods of knowledge organization these companies utilize in order to organise lessons learned and improve cooperation for future projects (Bartholomew, 2008). Additionally, Wheeler considers the existence of feedback tools essential for sustainable design (Wheeler, 2013). Even though large design and construction companies make good use of the abilities that technology offers, on the "Edge" building in Amsterdam for example (BREEAM, 2016), building evaluation methods are not used widely enough in order to succeed an important effect to the actual built environment.

Research in building evaluation methods dates back to the early 1960s. It was at that time that the Royal Institute of British Architects (RIBA) introduced "Stage M: feedback" on the final part of the "Plan of work for Design Team Operation" guideline (Royal Institute of British Architects, 1963). Since then, research on the subject has focused on the procedures needed. Different methods were designed to fit different building types and different purposes at the time.

In 1965 a very exhaustive study was conducted at the Cooperative Insurance Society building in Manchester, which was completed in 1962. After an exhaustive analysis of the building, the researchers approached the staff, in order to understand those features in the building that are

influential in determining a person's subjective reactions to his workplace. The staff provided their views on the building through questionnaires and interviews. The conclusions of this research focused on architectural and interior design and building quality (Manning, P. N. et al., 1965).

A study of high-rise dorms in Berkeley, published in 1967, introduced the research in the behaviour of the dorm residents as a deciding factor for the use of the building. The researchers used questionnaires, activity logs, diaries and sketches drawn by the respondents in order to understand the main factors that affect the design of the dorms during their use. It may be one of the first times that a similar research included psychological factors in its findings. The institutionalisation feelings the students experienced created a negative approach to the building. The inability of the students to intervene with the room design created additional frustration and feelings of impersonality. The students refrained from using the common rooms and preferred to use the corridors for socializing. The findings of this research resulted to comments on the university housing policy and the academic needs of the students (Ryn, Van der et al., 1967).

In 1972, the Building Performance Research Unit, based in the University of Strathclyde, focused its research on school buildings, a choice made mainly on the convenience of the field. They published the methodological analysis of two cases and gathered data from 28 UK schools. The main focus was the connection between the building and its users. As a result, any construction or design fault would have "real, human consequences". Data was collected by 510 teachers by the use of questionnaires and the issues addressed included examination of building services, structure and condition, occupancy schedules and environmental factors (Markus et al., 1972).

Another subject that was looked into during the 1970s was the safety of domestic areas. Research that had taken place in the early 1970s examined 100 housing projects in terms of links of design with crime (Preiser et al., 1989). Findings of this research included issues on the design, the public or private character of public spaces, the size and number of apartments in buildings, their management and condition and the socioeconomic characteristics of the residents (Newman, 1996).

One project that concerned a domestic building was included among other building types in a 1978 research publication that presented the general characteristics of environmental design evaluation research. Rather than searching the cause, the research aimed to understand the influences that led to the condition of a space or building. Again in this case, the 220-unit apartment complex was evaluated in an effort to understand how the design decisions were made and how the residents used and felt in their homes. This study again found that sociopsychological and design factors were the main influencers for occupant satisfaction (Friedmann et al., 1978).

Another approach towards the understanding of the factors that affect the building during its lifetime was presented in 1984, which examined use by-products and adaptations, displays of the self of the user, public messages and voluntary and involuntary behavioural patterns that emerge in different spacial formations. This research seems to be the first to propose an interdisciplinary approach to building evaluation, as it includes a psychological aspect in behavioural analysis (Zeisel, 1984).

The 1980s marked a significant change in the approach taken to the evaluation of buildings. The introduction of the sustainable development agenda and the energy crisis that took place during the decade provided additional momentum to buildings research.

Research into what came to be the Building Use Studies (BUS) methodology has its roots around 1985. Early trials like the Office Environment Survey attempted to create an understanding on how extended was the Sick Building Syndrome (SBS) phenomenon at the time. More than 4.000 workers

in 46 buildings responded to a questionnaire survey on their sense of the working environment and different symptoms that were common with the SBS (Wilson, 1987). Other questions referred to the following subjects: environmental comfort, satisfaction with amenities, time spent in building, time spent at task, productivity and background data. By 1995, the survey had taken place at 120 buildings and the researchers had gathered a database of more than 10.000 respondents (Leaman, A., 1995).

The facilities management focus of the practice of building evaluations that begun with the BUS methodology and continued with research published in the United States (Preiser et al., 1989), boosted research in the sector but took the focus away from domestic buildings. The BUS methodology evolved and the research group started working on the Post-occupancy Review Of Buildings and their Engineering (PROBE) initiative. It incorporated a series of stages that included different types of questionnaires, site visits, the BUS occupant survey, energy analyses and an air leakage pressure test (Cohen et al., 2001).

The PROBE studies initiated a strong momentum in the field. The Energy Analysis Reporting Methodology (EARM) that was introduced by these studies was adopted by the Chartered Institution of Building Services Engineers (CIBSE) to become the first edition of the Technical Memorandum 22 (TM22: 1999). TM-22 was a three-stage process and during each stage it looked into different depths of the building. Initially, it broadly analysed simple annual consumption indices by fuel. The intermediate level, reserved for more complex buildings, considered occupancy, weather and unusual energy uses. The advanced level of study was intended for detailed assessment of the building. It included energy load pattern analysis and occupancy schedules. The 2006 revision focused even more on the energy performance of buildings in an effort to implement the relevant EU Directive (CIBSE, 2006).

The TM-22 focus on the energy consumption of the building as a method of assessment of its performance though, diverted from the focus on architectural design, construction quality and endurance, issues that the earlier methods incorporated. The occupants had now disappeared from the equation and had become a behavioural research subject in order to be included in simulation software. The research now had focused on finding a way to predict the use of the building elements that mattered to the results of the simulation software. Research now sources data from databases concerning the use of windows, blinds, lights, heaters and fans in 25 buildings around the world. It then tries to analyse them in comparison to outside temperature data in order to feed the results to thermal simulation models for buildings (Nicol, J. F., 2001). In the same manner, mathematical models are utilised in an attempt to find the probability of the ways building occupants might respond to thermal discomfort (Nicol, J. F. & Humphreys, 2004). Other research uses real time energy load demands and temperature readings combined with existing behavioural models in order to predict thermal comfort in office spaces (Hoes et al., 2009). All these and many other studies (e.g: (Seryak & Kissock, 2003; Garg & Bansal, 2000; Bourgeois, D. J., 2005; Clarke, 2001)) that try to predict human behaviour and import it to even more complicated building simulation models emphasise the importance of the human factor but fail to produce a viable and reliable prediction model. As a result, when one research team attempts to list one set of factors, they are forced to ignore other equally or even more important ones due to inability to process all of them and include them in inclusive mathematical models, for example: (Langevin et al., 2015; Masoso & Grobler, 2010; Nicol, F. et al., 2012). Additionally, research is mostly conducted in controlled office, educational and/or cyber/ simulation spaces, while the domestic sector is largely ignored.

The change of focus

The change of focus that happened during the 1980s and has followed the evaluation methodology ever since, has led to the serious problem that the sector faces today: a significantly limited amount of building evaluations taking place. Published research pinpoints the different criteria that designers and occupants use to evaluate a building (Zimmerman & Martin, 2001). Similar differences were also identified by the PROBE team (Cohen et al., 1999). The main barriers that research presents is the lack of economic incentive for the designer, the willingness from the part of the developer to minimise the costs, the inability to allocate the responsibility and repair costs and the limited benefits that arise from the evaluation for each building or part of a building (Zimmerman & Martin, 2001).

The research gap in domestic buildings

This review of the research in the subject shows that priority has been given to non-domestic buildings (Leaman, A. et al., 2010). Reasons for this focus are likely to be ease of access, control and critical mass in costs, population and use of spaces. The case of "The Edge" building in Amsterdam, designed by PLP Architecture is a clear example of the technological possibilities that can be introduced in an office building, using technology available today (BREEAM, 2016). Time will only tell whether this example of integration of technology and architecture will actually work and provide for its promises of sustainability and usability (PLP_Architecture, 2016). The data, though, that will be available by the use of the building is one of the most important challenges that its managers will face. In-use data and the detail that it will entail is likely to make the distinction of the important patterns very difficult. In addition to this, there seems to be a turn to automation while user comfort and understanding of behaviour constitute issues that are not given priority, mainly due to their complexity. Unfortunately, the same problem exists in the housing sector (Leaman, A. et al., 2010).

Going back to the research deficit that concerns the performance of domestic buildings (Leaman, A. et al., 2010), a substantial gap exists in research that needs to be covered in order to complete any steps towards the purposes of sustainable development agenda and the Paris climate agreement of 2016. The need to focus on the domestic sector has already started being addressed in the UK, though. Schemes like Innovate UK's "Retrofit for the Future" and Building Research Establishment's "Home Quality Mark" are efforts that point to the right direction and aim to tackle the issues that affect the larger parts of the built environment. Their practice, though, remains limited, as "Retrofit for the Future" resulted in the retrofit of just over 100 domestic buildings (Technology Strategy Board, 2013) and "Home Quality Mark" is still in research and development stage (BRE, 2015). On the other hand, Energy Performance Certificates (EPC) that are required by law for the construction, purchase or lease of domestic properties have not had important effect on their purpose. Research on the impact of EPCs has shown that energy efficiency plays minimal role in the homebuyers' decision-making process, while their majority do not undertake the proposed retrofitting suggestions (Watts et al., 2011).

CONCLUSION

Soft Landings and its possibilities

The impact and effectiveness of the PROBE studies evolved to the currently used Soft Landings Framework. Its success resulted to the acceptance of the framework by the UK Government which introduced the Government Soft Landings, an interpretation of the framework aimed at centrally funded projects.

The framework's non-domestic roots have followed the process until today. Even though the official directives and publications for the framework do not explicitly exclude domestic buildings, the whole process is designed for non-domestic application. Taking into consideration the fact that in 2015 alone, planning permissions that concerned dwellings were 14.85% of the total developments in England, as opposed to 0.64% that concerned office buildings (Government, 2015), any efforts to improve the performance of office buildings would have minimal effect to the purposes of any sustainability legislation.

The design stages that the Soft Landings Framework introduces are similar to the RIBA plan of work and constitute a good start for the design of domestic buildings. Even more, the end users of the building could be more accessible, more willing to complete the stages of the process efficiently and even extend the aftercare period beyond the three year period that the framework aims for (Way et al., 2009).

One of the most usual complaints in the sustainable design and construction sector concerns the unwillingness of the occupants, whatever the building use, to comply or even understand the scenarios and strategies the designers have implemented to the building. There is a need for a simple method that could inspire and convince the domestic building users to understand the benefit of these strategies. The Soft Landings Framework is a simple, easy to use guideline that has been adopted by the UK Government. It aims to engage as many stakeholders as possible in the design process. A new Soft Landings version, appropriate for domestic buildings, is required. It needs to be informed by the factors that building evaluation methodology has examined traditionally in order to cover the whole complexity of the building's lifetime. More widespread use of such a framework would significantly benefit the market and inspire a cultural change towards the more efficient use of our homes and eventually, more sustainable lifestyles.

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EXPLORING THE IMPLEMENTATION OF A SUSTAINABILITY FRAMEWORK AT CUT

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Keywords: Building, Higher Education, Operations, Sustainability.

ABSTRACT

Ecological and carbon footprint measurement outputs imply that a 'Business as Usual' (BAU) mode of living and consumption is unsustainable. To tackle BAU issues many initiatives are underfoot at non-academic and academic institutions. The reversal of BAU is also supported with the work of universities in terms of teaching, learning, research and operations. This is the case at the Central University of Technology, Free State (CUT), South Africa where a framework is the umbrella document used to promote sustainability. This theoretical paper reports on on-going efforts at the university through the use of three case studies conducted in the Department of Built Environment in 2015. These cases on implementation efforts uncover the drivers of sustainability on the main campus of the university while making a strong case for the review of the organisational culture, which should in turn encourage the retrofitting of existing non-residential buildings of the university. The discussion of the cases highlights the ways in which the sustainability framework of the institution could use sustainable principles to 'walk the talk', going forward.

BACKGROUND

The application of sustainable development (SD) ethos has continued to resonate in contemporary society. The application is predicated on high ecological and carbon footprint measurement outputs, which further reiterate the unsustainable nature of society's mode of living and consumption. This inadvertently indicates that the 'Business as Usual' (BAU) approach to living undermines SD to the extent that a reversal is essential. SD has assumed multi-faceted dimensions, spanning various economic sectors. Various actors, ranging from non-governmental institutions to academic institutions as well governmental organisations and private organisations have continued to embark on measures expected to propel its advancement.

Among these actors, much is expected from academic institutions, particularly Higher Education Institutions (HEIs), in spearheading this desire for societal transformation towards SD (Cortese, 2003; Krizek *et al*., 2012; Lozano *et al*., 2013). This expectation is genuine, considering the role of HEIs, both as centres of knowledge creation and dissemination as well as societal change agents (Stephens *et al.*, 2008; Ralph and Stubbs, 2014). But, efforts of HEIs in this regard has enjoyed insufficient reportage, especially in Sub-Saharan Africa (SSA) (Escrigas *et al.*, 2011). On the contrary, HEIs in other continents have continued to enjoy incremental levels of sustainability reporting, hence making terms such as 'Education for Sustainable Development' (ESD), 'Green Campus', and 'Sustainable University' (SU) commonplace in the HEI lexicon. Still, most of what is reported in these HEIs focuses on the integration of sustainability principles into certain facets of teaching and learning, and research based activities (Ferrer-Balas *et al*., 2008; Svanström *et al*., 2012). In other cases where the operations facet is featured, there is a noticeable absence of a systemic whole-of-campus approach (McMillin and Dyball, 2009). Arguably, this has been found to be counter-productive as it makes successful SD implementation difficult, if not impossible. McMillin and Dyball (2009) propose the development of a campus wide systemic implementation framework as a panacea for this imbroglio.

This proposal from McMillin and Dyball (2009) brings the rationale for this paper into focus. The Central University of Technology, Free State (CUT) in Bloemfontein, South Africa belongs to the comity of few HEIs in SSA to have indicated willingness to transform into an SU. This willingness has metamorphosed into a strategic vision statement entitled the 'Sustainability@CUT' (CUT, 2012). To ensure the unhindered attainment of the objectives of this vision, a framework was developed to drive implementation. However, mid-way into the proposed implementation timeline, the paucity of information on implementation activities has triggered calls for an investigation into implementation performance. This is a gap which this on-going research from the built environment angle is seeking to bridge. It is expected that findings from such efforts will contribute to enabling optimal implementation.

Subsequent sections of this paper consist of: a highlight of the research methodology, a description of the case studies and their findings. A discussion of the implications of the emerging findings and associate conclusions ends the paper.

RESEARCH METHODOLOGY

This study adopts an embedded single case study approach owing to this approach's proficiency when studying a phenomenon (the implementation of the sustainability framework) within its natural context (CUT) (Yin, 2009). This approach entailed the utilisation of three distinct cases within a wider single case study context as typified by the CUT, hence availing the researchers with more than one sub-unit of analysis. For this study, the authors relied upon three separate case studies carried out by undergraduate students and a post-doctoral fellow in the Department of Built Environment in 2015. Whilst the first two cases, entitled 'Exploring the drivers of Sustainability at Central University of Technology, Free State' and 'Retrofitting existing buildings at the Central University of Technology at Bloemfontein Campus' were carried out by a cohort of undergraduate students, the third case study forms part of a wider study and is entitled 'An Identification of Organisational Factors Affecting Sustainable Development in a South African University' conducted by a post-doctoral research fellow at the department.

The two undergraduate case studies were selected from seven sustainability projects executed as part of the stipulated requirements for the research methodology subject at the Department of Built Environment in 2015 (Figure 1). The selection criteria adopted was predicated on a range of predetermined factors such as adequate representation of the views of stakeholders to the CUT's SU agenda implementation in the data, as well as ability to satisfy the objectives of this particular paper. The data for this study were generated from the selected case studies through a Qualitative Content Analysis (QCA). The use of QCA emphasises an integrated view of texts in their specific context; and it goes beyond merely counting words from texts to examine meanings, themes and patterns that may be manifest or latent in a particular text (Zhang and Wildemuth, 2009). Subsequently, the emergent findings from the cases were drawn upon to provide an exploratory perspective on the implementation of the sustainability framework at CUT.

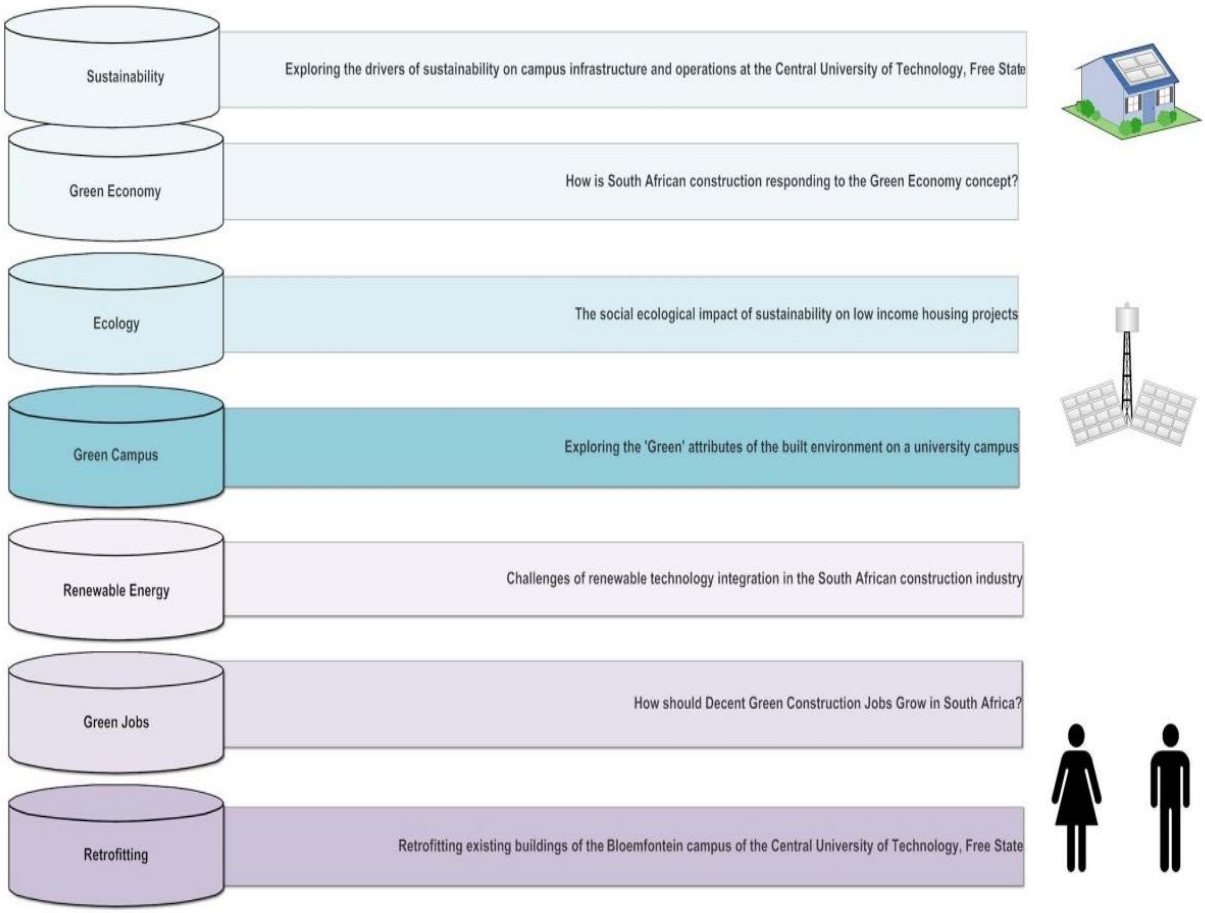

Figure 1: Sustainability related undergraduate projects in 2015

CASE STUDIES ON SUSTAINABILITY IN CUT

The selected studies are applied as single case studies addressing the main objective: to explore the implementation of the sustainability framework at CUT. Excerpts of these cases are detailed below.

CASE 1: **Exploring the drivers of sustainability at CUT**

An identification of internal drivers is essential in securing the commitment or buy-in of the entire HEI community towards the attainment of the SU ambition. Predicated on this proposition, a cohort of undergraduate students commenced an exploratory study into identifying the drivers of sustainability at the CUT. The study started by acknowledging the challenges of the implementation of sustainability in HEIs in the present age.

Furthermore, they also confirmed the need for the investment in the purchase or upgrade of extant technologies, which would lead to effective utilisation of resources at HEIs to support the SU bid. As part of its declared mandate, the study highlights its desire to understand stakeholders' perceptions as well as the degree of awareness exhibited by these stakeholders concerning sustainability within the CUT and to identify and measure the degree of import of the identified drivers. The undergraduate researchers posit that the integration of more sustainability concepts at CUT will lead to an eventual reduction in operating costs, particularly costs associated with energy and water

usage. Through a robust review of the literature, the study buttresses the importance of SD in tackling issues such as poor waste management, climate change, and ineffective utilisation of resources, among others. Relying on a single case study approach, the study was able to focus on gaining an in-depth understanding of sustainability at CUT and the drivers responsible for it.

A mix of face-to-face interviews and observation were adopted as appropriate data collection techniques. Twenty-five (25) interviews were conducted from an initial sample of eighty (80) interviewees. These interviewees were purposively selected. The selected sample consisted of a staff member at the sustainability office, 15 students from the management science faculty, two students from the health faculty, six students from the faculty of engineering, and one lecturer from the faculty of engineering. Prior to the commencement of the interviews, an interview protocol was drawn up to serve as a guide for the interviewers. The layout of the protocol used is shown in Table 1.

Table 8 Layout of the Interview Protocol

S/N	Theme	Questions
1	Comprehension of sustainability on campus	3
2	The perception and level of awareness on sustainability	3
3	Exploring the degree and significance of identified drivers of sustainability	2

The interviews were recorded and transcribed verbatim. The transcripts were analysed thematically. This implied the usage of pre-set themes in coding the emergent data. The themes are also indicated in Table 1 and are subsequently used in presenting the findings of the study.

Theme 1: Comprehension of Sustainability on Campus

Based on the available data, it was observed that there was a low understanding of what sustainability on campus actually entailed. This was especially so on the part of the students. According to a vast majority of student interviewees, the term sustainability on campus meant the HEI's ability to sustain its day to day activities and enable it to continue to do so in future. Other interviewees such as the staff member at the sustainability office of CUT associated sustainability with the issues, which had been hitherto outlined in the sustainability framework of the university. These issues range from financial assessment, reduction of energy and fossil fuel usage and effective waste management through recycling. However, the study acknowledged recent developments on campus such as the infrastructural facelift, and the enhanced utilisation of renewable energy devices on campus. Adding these developments may lead to a better comprehension of the sustainability on campus amongst the various stakeholders within the CUT.

Theme 2: Perception and Level of Sustainability Awareness

The data shows that a low level of awareness concerning sustainability was observed among almost all the interviewees. As such, this observation impacted adversely on the perception of the various stakeholders on SD within the campus. A modification of the extant approaches to teaching and learning was suggested as a potential panacea to reversing the state of affairs. Furthermore, possible indicators of the sustainability on campus were identified as comprising of electricity consumption, water consumption and cleanliness of the university environment.

Theme 3: Significance of the Identified Drivers of Sustainability

The study identified climate change, the need for effective management of renewable resources, economic developmental issues, the need for increased connectivity and communication as the major drivers of sustainability in the CUT. Beyond an identification of the drivers of sustainability at CUT, the study proceeds to conclude that more efforts need to be expended by CUT in improving the level of awareness of sustainability as well as comprehension of sustainability-based campus initiatives, which were discovered to be low.

CASE 2: Retrofitting existing buildings of CUT at Bloemfontein Campus

This study was predicated on the need to explore the potentials of retrofitting in curbing the energy inefficiencies experienced among non-residential buildings in the Bloemfontein campus of CUT. Occasioned by the prevalence of unsustainable non-residential buildings on the campus, and increasing energy costs, this study proposes that retrofitting existing non-residential buildings will lead to an improved degree of energy efficiency in CUT. The potential of these non-residential buildings to cause debilitating effects on the university's SU ambition due to high carbon footprints and unfavourable indoor environmental quality rendered this study imperative. In a nutshell, it was expected that the findings from this case would promote ways to begin a rethink of how to improve energy efficiency, reduce carbon footprint and improve indoor environmental quality in the identified non-residential buildings.

To achieve this objective, this study adopted a phenomenological pathway, employing a mix of interviews and questionnaire surveys. The HEI's facilities director featured prominently as one of the interviewees. An unspecified number of questionnaires were distributed to members of the university community to elicit their views. Questions asked pertained to the current state of energy efficiency, carbon footprint and indoor environment quality as experienced in these non-residential buildings. The data collection process took three months. The data emerging from the interviews were transcribed and analysed, thematically. Descriptive statistics was applied in the analysis of the questionnaire based data. The two sets of data were utilised in such a manner as to enable complementarity.

Findings from this study highlight the unsustainable state of non-residential buildings on the Bloemfontein campus vis-à-vis energy efficiency, carbon footprint and indoor environment quality. Of particular concern to a majority of the respondents was the issue of poor indoor environmental quality. They posited that this phenomenon alone ebbed productivity levels among staffs and students. This is to be expected considering the direct relationship, which exists between the learning environment and student productivity. Also, it was observed that issues pertaining to energy efficiency and carbon footprint output were of utmost concern to staff of the university's facility management directorate. This concern stems from the associated factors such as high energy costs and the anticipated commencement of the Carbon Tax policy in South Africa. These costs would drastically lead to a disproportional increase in the running costs of the university as well as contribute to the unsustainable mode of living, thus negating the SU vision. In brief, this study underscores the importance of retrofitting existing old non-residential buildings in enabling a sustainable environment as is typical of an SU.

CASE 3-An Identification of organisational factors affecting sustainable development in a South African University

This study forms a constituent part of a wider post-doctoral research study entitled 'Towards a Viable Implementation of the Sustainability Agenda: A Systems Approach to (Re) Designing the Infrastructure Client (CUT's) Business Model'. For the purposes of the present paper, representations from this research are restricted to the identified case and not the entire post-doctoral study. In this particular case, a review of the state-of-the-art literature led to the identification of various factors, categorised as organisational and financial factors, which have the potential to affect the implementation of SD in HEIs (Table 2).

Table 2: Factors influencing SD Implementation in HEIs

Category	Factors	Authors
Organisational	Collaboration (Stakeholder Collaboration / Staff Commitment / Student Partnerships/ Collaborative Decision-making / Presence of Silos)	Lozano-García *et al.* (2009), Ralph and Stubbs (2014), Stafford (2011), Sharp (2002), Shriberg (2002), Sharp (2009), Cortese (2003), McMillin and Dyball (2009)
	Leadership (Strategic Vision / Support from Top Level Management / Visionary Leadership) Incentive Structure/ Connectors to Society/ Coordination Units and Projects/ Sustainability Champions/Organizational Structure/Societal Pressure)	Ferrer-Balas *et al*. (2008), Velazquez *et al*. (2005), Luo and Yang (2012), Sharp (2002), Velazquez *et al*. (2006)
	Communication (Communication of the Sustainability concept)	Luo and Yang (2012), Sharp (2002), Djordjevic and Cotton (2011), Adomssent *et al. (2007)*
	Knowledge (Degree of Innovativeness/ Understanding/ Awareness/ Experience/ Skills)	Ferrer-Balas *et al*. (2010), Velazquez *et al*. (2006), Luo and Yang (2012), Ralph and Stubbs (2014),
	Behavioural (Appreciation of the Value of Outreach Activities within Academia/Level of Freedom exercised by Faculty Members/ Desire to Change)	Ferrer-Balas *et al*. (2008), Ferrer-Balas *et al*. (2010), Luo and Yang (2012), Ralph and Stubbs (2014), Shriberg (2002),
	Physical (Organizational Size)	Stafford (2011) Ferrer-Balas *et al*. (2008)
Financial	Finance (Financial Constraints/ Consideration of Life-Cycle Savings During Budget Modelling/Source of Funding)	Luo and Yang (2012), Stafford (2011), Velazquez *et al*. (2006), Ralph and Stubbs (2014), Ferrer-Balas *et al*. (2010), Ferrer-Balas *et al*. (2008)

Relying on a qualitative single case study of the CUT, this study set out to identify the organisational factors affecting SD implementation within the HEI. These organisational factors were applied in developing pre-set themes to enable easy analysis. The themes so developed include collaboration, leadership, communication, knowledge, behavioural, and physical factors. Equipped with these

themes, the promoters of the study proceeded to choose appropriate data collection techniques for achieving its core objective. Techniques such as semi-structured interviews, review of documents as well as participant observation were adopted. The ability to utilise these techniques in a single study was enabled by the choice of the case study approach. Interviewees were purposively and conveniently chosen according to a set of laid down criteria. Care was taken to ensure adequate representation of all stakeholder groups of CUT. Twelve (12) interviews were successfully conducted and used in this study. A description of the interviewee demographics is rendered in Table 3.

Table 3 List of Interviewees

No.	Interviewee Code	Stakeholder Group
1	CON	Consultants
2	OPS1	Operations
3	OPS2	Operations
4	OPS3	Operations
5	SM	Management
6	SL	Academic
7	JL	Academic
8	CM	Contractor
9	GFC	Contractor
10	PS	Postgraduate Student
11	PS2	Postgraduate Student
12	US	Undergraduate

Questions asked related to: understanding of the SD concept; level of awareness about CUT's SD agenda; perceptions of the agenda; and barriers and drivers of successful implementation of SD at CUT. The interviews lasted for an average of forty-five (45) minutes. Thereafter, these interviews were transcribed. During this time, the second author of this paper was also involved in three (3) meetings with some stakeholder representatives wherein deliberations concerned the issue of SD implementation within CUT. Two of these meetings had in attendance CUT's SD manager. At these meetings, the second author made notes. Also, documents pertaining to CUT's SD agenda were perused for background information. The pre-set themes identified previously were used in coding the emergent data. The findings are detailed under these themes in the next sub section of this paper.

Theme 1: Collaboration

Silos need to be abolished for proper stakeholder collaboration to occur. Within the CUT, the existence of silos within the academic community and the operations departments as well as between these departments was observed. This has led to continuous disagreements about the best approach to SD implementation. For instance, at one of the sustainability themed meetings concerning the conduct of interdisciplinary research, the participants from the academia (from different faculties) failed to arrive at a consensus. Every person had a different view on what the subject of the research should be premised upon in apparent defence of personal / individual discipline. The operations community does not fare any better. During one of the interview sessions with OP2, it was observed that she was unaware of the university's SD agenda. Buttressing OP2's statement, CM explained that there were no interactions between the CUT (client), the consultants and the contractor during design development for infrastructure projects. As such, he was also

unaware of any SD agenda at CUT. These instances point towards non-collaborative working among the stakeholders in the university.

Theme 2: Leadership

It was observed that whereas the university's management have continually declared their willingness to lead the HEI towards the attainment of a SU status, their actions or inactions have often been discovered to be at cross-purpose with such declarations. From the perspective of infrastructure procurement for instance, it was observed that BAU has remained the norm. No noticeable change was observed to indicate support from management for the integration of SD principles and concepts into projects both at design and construction stages, besides the insistence for the channelling of 30% of construction spend on local supply chain members. Specifications stipulating the use of materials and practices that are associated with SD were absent from contract documents. Issues relating to initial project cost have continued to guide management decisions to embark on new projects and contractors' engagement. It was also discovered that life-cycle savings were not an attractive proposition for management decisions. Management's inability to ensure compliance to sustainable procurement of goods and services at the university was also at variance with SD.

Theme 3: Communication

Good communication is essential considering the compartmentalised nature of HEIs. Silos can only be dismantled with the aid of effective communication. From the emergent data, the absence of such an effective information sharing channel as it pertains to the dissemination of SD related information at CUT was observed. Most interviewees feigned indifference and / or lack of awareness of SD agenda in the HEI.

Theme 4: Knowledge

Furthermore, SD related skills are essential within the operations department if optimal SD implementation is to be achieved. It was evident from the data collected that CUT was making a conscientious effort towards the integration of SD principles into its teaching and learning curricula. SL admitted that the integration of SD into the curricula was currently on-going whereas SM alluded to the conduct of workshops to equip staff involved with operations at CUT with the requisite SD related skills. However, CON cited the absence of such competencies within CUT necessary to engender SD, particularly from an operations perspective.

Theme 5: Behavioural

Interactions with various stakeholders revealed a lackadaisical attitude by US1, US2, and PS. The same attitude was observed by OPS3 as they feigned ignorance of anything associated with the SD theme. Whereas other interviewees indicated their awareness of SD ethos and their responsibilities towards the attainment of successful implementation, it was observed that they were merely stating this from an organisational perspective. It is unclear whether they have, as individuals, imbibed the SD ethos.

Theme 6: Physical

This stands to CUT's advantage as it is a smaller HEI when compared to most of its peers. As such, the implementation of SD need not be an arduous task. Nevertheless, there is no evidence yet from the data obtained thus far which signifies that CUT's size has proven to be of advantage as it pertains to the implementation of SD.

DISCUSSION

The university's desire to assume an SU status would be complemented by an identification of the internal drivers propelling such an ambition. Whilst the extant literature accentuates that pressure from the external society is mostly responsible for the decision of HEIs' desire to transform into SUs, it further reiterates the significance of internal drivers in ensuring that the HEI stays the course and sustains the vision (Velazquez *et al*., 2005; Sharp, 2009). As noted in the previous section of this paper, internal drivers at CUT include communication, climate change, renewable resources, connectivity, and communication. While communication emerges as a crucial element of sustained move towards sustainability at CUT from case study 1, the lack of it that was reported in case study 3 is a major gap. This gap should be bridged as successful SD implementation is dependent upon the ability of HEIs to effectively communicate its SD agenda to all stakeholders (Djordjevic and Cotton, 2011). Effective communication is crucial because it would enlighten stakeholders regarding responsibilities expected from them (Svanström *et al*., 2012).

The reported low understanding and awareness levels of sustainability among most of the stakeholders at CUT could be revised through curricula renewal and new approach to operations. Although HEIs have been criticised over the lack of a dynamic approach to innovation because of the manner in which they have proceeded in curricula development and research has also been identified as an encumbrance to successful SD implementation from a teaching, learning and research dimension (Krizek *et al*., 2012; Cortese, 2003; Sharp, 2009), there is a need to enhance the level of understanding and awareness of sustainability principles in universities that profess SU ambition. Increased awareness at such institutions would alter organisational culture, which plays a major role in work performance and effectiveness, and also stand as the summation of behaviours, beliefs, values, norms, and systems in an enterprise (Zhang and Liu, 2006). Given that it has been reported to pose a major threat to the implementation of SD (Emuze, 2015), the behavioural aspect uncovered in the 3rd case study should be addressed because of its ability to drive operational decisions concerning use and procurement of facilities in each university.

CONCLUSION

In recognition of the important roles of universities regarding the promotion of SD and reversal of BAU issues, CUT is making strides to join the growing number of institutions known as 'SU'. With the use of a framework that seeks to embed institutional sustainability, the university appears to be making efforts to transform into SU. The drivers of these efforts are common and appear to point to the gaps in the implementation. So far, case studies are reporting low levels of understanding and awareness among the people that should be driving the implementation of the framework. Such levels of understanding and awareness perhaps suggest a need to upscale communication, apart from curriculum innovation and renewal. Another aspect of significance is the retrofitting of existing

non-residential buildings so that improved indoor environmental air quality that is pertinent for increased workplace productivity can be enhanced. To sum up, it is apparent that there is enough scope for enhanced implementation of the framework based on the findings that are emerging from the various studies that began in 2015.

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Materials, Products and Sustainability

MEASURING THE EMBODIED CARBON CONTENT OF CONCRETE PAVING

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Keywords: embodied carbon, embodied energy, energy auditing, concrete paving

ABSTRACT

This paper summarises the outcomes of a PhD research project by Richardson (2009) to measure the embodied carbon content of concrete paving and to reveal the barriers to its accurate measurement. This is a current area of research due to the concerns arising from the anthropogenic emission of carbon dioxide which has been identified as a key cause of climate change. The work was carried out in co-operation with a major manufacturer of concrete paving revealing the practicalities of energy auditing within an existing factory using its unmodified infrastructure, methods of energy metering and recording. The work involved identifying all of the energy inputs involved in the manufacturing process during a financial year. The auditing boundaries were restricted to the main manufacturing facility and its immediate suppliers of raw materials commonly known as cradle to gate. The energy applicable to the paving material had to be apportioned from site wide energy usage. The energy used to supply the raw materials and operate the manufacturing facility was then converted to an amount of carbon dioxide released using standard conversion factors. The barriers to accurate auditing were identified and an embodied carbon coefficient for the raw materials and finished product determined. The embodied carbon contents that were determined differed from those found in the national database. A number of factors are identified that could have contributed to this and suggestions for further research made.

INTRODUCTION

It is now widely accepted by the scientific community that the release of carbon dioxide (CO_2) into the atmosphere from fossil fuel based energy use is a major contributor to climate change. In the United Kingdom (UK) the construction and operation of buildings has been identified as supplying almost half of the CO_2 discharged into the atmosphere each year (Drummond, P., & Ekins, P. 2016). It can be seen then that reducing the energy used to construct and operate buildings is key to reducing the overall UK CO_2 output. To date, the main focus has been given to reducing the energy used in the operation of buildings. In the UK this is primarily consumed by space and water heating systems but also includes other building services installed in the premises including, lighting, fans and pumps and in some buildings air conditioning and mechanical movement systems. Much legislation has recently been implemented to reduce the operational energy use of new buildings. This includes changes to Part L of the Building Regulations (Department for Communities and Local Government 2016) which includes elements of the EU Energy Performance of Buildings Directive (European Union 2010). The aim of this legislation is to reduce the CO_2 output arising from fossil fuel energy consumption in buildings with an ultimate aim of producing zero CO_2 buildings. For example it was the UK Government's target to reduce the carbon output of new housing to zero by 2016 (Department for Communities and Local Government 2009). This ambitious target has now been relaxed but if it were to be achieved then the focus of attention would shift onto the energy used and hence CO_2 emitted during the extraction and manufacture of materials and the construction of buildings from those materials. Even with low but not zero CO_2 buildings it has been estimated by Troy, P., Holloway, D., Pullen, S., & Bunker, R. (2003). that, in some buildings, embodied carbon will be greater than the amount of operational carbon for many years and in some cases, with short building lives, may be the dominant energy use over the whole life of the building.

A number of studies have considered the issue of embodied energy previously including Miller (1997), Alcorn (1998), Miller (2001) and Scheuer, Keoleian, & Reppe (2003). This study adds to that body of knowledge by focussing on a specific product and continues moving the focus of attention from units of energy used to amount of CO_2 released. This is important because the amount of CO_2 released is a better indicator of environmental impact than the number of energy units consumed. This is because the consumption of different forms of energy results in the release of different amounts of CO_2. For example 1kWh of energy from a renewable source, such as wind power as a result of its embodied energy releases very little CO_2 whereas the same unit of energy from a highly processed source such as mains electricity results in the release of a relatively large amount of CO_2 into the atmosphere.

The research was carried out in collaboration with a local manufacturer and their raw material suppliers. At the time of the research the works had a long history, having been first established to produce natural stone products. It now produces a range of concrete based landscaping and building products for the international market. The operators of the site are very environmentally aware and are constantly seeking ways of reducing the environmental impact of their operations. Part of this ongoing commitment was to collaborate with this research project. The site is a useful choice for this project in that it is a well-established site, reflective of much of the UK manufacturing infrastructure. It has the added complexity, again shared by other manufacturers, of using the same plant to produce more than one product.

The product that is the subject of this research is the natural (uncoloured) pre-cast concrete paving slabs. This is referred to throughout the text as 'concrete paving'. The embodied carbon content arrived at through this research will be compared with figures contained in the authoritative Inventory of Carbon and Energy Database (Hammond & Jones 2008)

The Auditing Boundaries

One of the decisions that has to be made when embarking on an embodied carbon audit is the need to define the boundaries between which the audit will be carried out. The simplest set of boundaries is those either side of the main manufacturing facility. This is because the energy used is more easily defined and simply requires the auditing of energy use, using the main utility meters and sub meters on site. However, the concern here is that the CO_2 output from suppliers of raw materials to the site remains unknown and with some materials this could be significant. For the purpose of this research it was therefore decided to include both the raw materials supply chain from the point of abstraction of the source materials from the environment (cradle) and the main manufacturing facility up to the point where the finished product exits the factory (gate) in the audit. The raw material suppliers can be identified from the components of the product mix, which are ordinary Portland cement, 6mm to dust sandstone, 5mm to dust limestone and mains water.

Energy uses beyond these boundaries, such as the supply of products and services to the raw material companies and main manufacturing facility, were not included in the audit. The reasons for this are twofold; the difficulty in identifying and auditing tertiary sources and secondly due to insignificant share of energy used in these sources when apportioned to each slab.

Direct and Indirect Energy Use

The energy needed to manufacture products includes both direct and indirect energy consumption. Direct energy use is defined as that required by the buildings, vehicles and the fixed and mobile plant that play an active part in the extraction, handling, processing and transportation events that form the material supply chain. Indirect energy uses are those events that occur in the background to support the direct activity. Both types of energy use are essential to the overall process as without them the supply chain could not function. Both direct and indirect energy use were audited.

Examples of Direct energy use are;

- Energy consumed by fixed and mobile plant to extract raw materials and transport them.
- Energy used to process materials for example crushing or heating.
- Energy consumed by fixed and mobile plant that is used to manufacture the finished product in the factory.

Examples of Indirect energy use are;

- Energy used to heat and light the stakeholder facilities.
- The maintenance of a stakeholder's buildings, plant and vehicles.
- Staff commuting, including those employed by outside catering, cleaning and maintenance companies.
- The heating/lighting of the administration buildings and running of office equipment.

AUDITING METHOD

A number of forms of energy are used across all of the stakeholders. Quantities of energy used were measured or had to be estimated. The range of techniques used to estimate energy consumption data included;

Vehicle fuel consumption
Fuel consumption was estimated by dividing the distance travelled in kilometres (km) by the vehicle fuel consumption obtained from the logistics manager, in kilometres per litre (km/l). When carrying heavy products such as stone the fuel consumption of vehicles is markedly different in the loaded and unloaded state. In this case round trip distance and the average of the loaded and unloaded fuel consumption was used. Round trip distances were obtained using on-line route planning software by entering departure and destination postcodes.

Electricity and gas
This energy input data was obtained from utility meter readings. However, in many cases the readings represented the energy used site-wide rather than exclusively for the production of concrete paving. This issue was applicable to both raw material suppliers and the main manufacturing facility. When this situation occurred, that part of the overall energy use related solely to the provision of a raw material or to concrete paving manufacture had to be estimated. This was carried out on a 'by weight' basis. Using the sandstone component as an example, the Quarry in question produced 510,000 tonnes of sandstone during the audit period 120,000 tonnes of which was the 150mm clean sandstone supplied to the Manufacturing Works, or 23.53% of total production output (personal communication made 19-04-07). It follows therefore that a reasonable estimate is to assume 23.5% of all Quarry energy used was associated with the concrete paving manufacture.

Raw Materials

This section gives a description of the energy using processes involved in supplying the raw materials required for the concrete paving to the manufacturing works. For most of the stakeholders a site visit was carried out to identify where energy was being consumed by the production process.

Cement
The Portland cement used to manufacture the natural concrete paving is sourced from a large UK Cement supplier. The main energy input events are; manufacture of the cement, transport to a distribution depot by rail and finally transport to the manufacturing works by road. Cement manufacture is a very energy intensive process requiring a number of energy input events (Lafarge Cement UK (LCUK) 2005).

5mm to Dust Limestone
The 5mm to dust limestone component of the mix used to manufacture the concrete paving is sourced from a quarry in the Yorkshire Dales National Park.

The primary processing of limestone extraction at the quarry uses much heavy plant such as tracked bucket loaders and crushers. However it is modern, well maintained and highly energy efficient equipment.

The secondary operation involves all further handling, processing and loading phases. This utilises conveyor belt systems, vibrators and tertiary crushers. The 5mm to Dust Limestone destined for the Manufacturing Works is collected from the silo and delivered by road by heavy goods vehicle (HGV).

150mm Clean Sandstone

The 150 mm clean sandstone component of the mix used to manufacture the concrete paving is sourced from the Manufacturer's own quarry in Lancashire. 120,000 tonnes of this are supplied each year.

The production of 150mm clean sandstone has been divided in to two specific operations; the primary operation involves pulling the rock from the quarry face using CAT 360^0 caterpillar tracked excavators. Where the rock is difficult, or too dangerous to dislodge using these machines, it is removed using explosives. The caterpillar tracked excavators then place the dislodged rock into a large stockpile.

The secondary operation involves two stages. The first stage, involves the use of two Daewoo 420 Breakers that use their hydraulic rammer to split the stone into blocks with edges around 600mm long. A tracked Loading Shovel then loads these into a primary Crusher. Subsequent to crushing taking place, the stone is conveyed to a screen to grade in to three sizes. The three sizes are 'Fine grains to 40mm', '75mm Clean' and '150mm Clean'. It is the latter size that is used at the Manufacturing Works and so is loaded onto waiting Class 1 HGVs using a tracked loading shovel.

This quarry is in an extremely remote elevated location having no access to any mains services. For this reason gas oil is the energy source for all the plant and generators that are used at this quarry. The quantity of gas oil that was consumed by the mobile plant is recorded on site via an automatic fuel monitoring system.

Water

A considerable amount of water is used to manufacture concrete products. The volume of mains water consumed at the Manufacturing Works is metered. The volume associated with the concrete paving was determined on the by-weight of total production basis described earlier. Ascertaining the embodied carbon dioxide content of mains supplied water would be difficult to determine from monitoring and so an accepted embodied energy of 1.2 kWh/m^3 was used (Coley, D.A. 1995). This was converted to a carbon dioxide output using the emission factor for electricity (0.43kg CO_2/kWh), based on the knowledge that electricity is the energy source used for treating, pumping and circulation of water.

Product Manufacturing Works

All of the raw materials are assembled into the final natural concrete paving product at the Manufacturing Works. This section looks at the direct and indirect energy used.

Direct energy usage

The manufacture of the paving product is comprised of the following three distinct direct energy demanding stages:

- Receipt, processing and handling of raw materials;

- Mixing, pressing, handling and curing of the finished product; and finally
- Packaging and handling of the finished product.

One element of the first stage that required a considerable amount of energy, involved crushing the 150mm clean sandstone down to the 6mm to dust product that is required by the mix. The energy required by the Norberg crusher is substantial and so has been sub metered. Meter readings are recorded at half hourly intervals. As an illustration, Figure 1 shows the electrical energy consumption of the crusher measured at half hourly intervals over a typical working day.

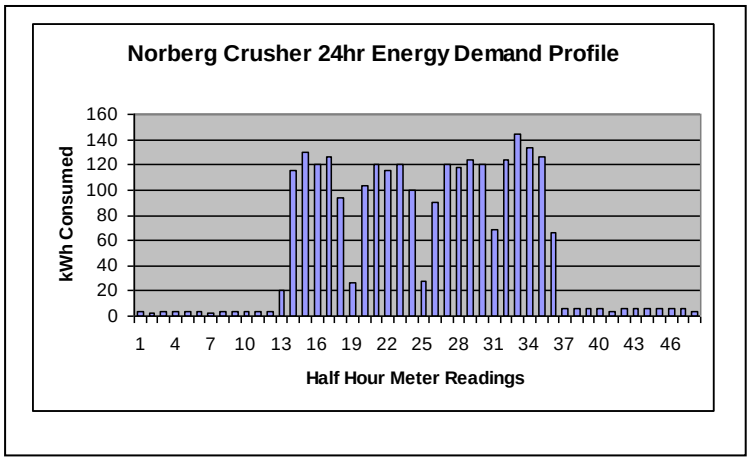

Figure 1: Norberg Crusher 24 hr Energy Demand Profile for one day.

From this figure it can be seen that on this day the maximum half hourly consumption was 144 kWh, the minimum consumption was 2 kWh and the total consumption across the whole 24 hour period was 2,566 kWh.

Production data and details concerning the fixed and mobile plant used, relating to the second and third direct stages, was provided by the Manufacturer and site visits. This information was used to construct table 1, so that the processes and plant involved could be more easily visualised.

Event	Item of Plant	Powered Components	Energy Source	Task being undertaken
Mixing source materials	Haarup mixer	Electric motor	Electricity 22 kW	Mix source materials with water to produce concrete
Transfer of concrete	Screw feed pipe	Electric motors	Electricity 1.5 kW & 4 kW	Screw feed pipe transfers concrete from the mixer to the paving press
Produce pavers	Paving press	Turn table Hydraulic press pump	Electricity 22 kW 22 kW	A three-mould turntable enables one mould to be filled, whilst one is being pressed and at the same time the paving product of the third mould is being ejected onto the tippler, which places the green paving product onto a pallet.
Transfer pallet of pavers	Fork lift truck		LPG	Once the required number of pavers has been placed on a pallet, they are then transported to the curing racks.
Curing the product	Curing racks		Natural gas	Curing of the paving product takes twelve hours, the process being enhanced by circulating warm air through the racks.
Transfer pavers to banding machine	Fork lift truck		LPG	
Bind pack of pavers	banding machine		Electricity 0.75 kW	In the case of the 450x450x50mm pavers, 40 units are bound together to form a pack.
Transfer pavers to the shrink wrap machine	Fork lift truck		Gas oil	
Shrink wrap pavers	Shrink wrap machine		Natural Gas	Pack of pavers is first placed on a timber pallet, before being wrapped in polythene by the shrink wrap machine. Product and Batch Code labels are inserted at this point.
Transfer pavers to yard	Fork lift truck		Gas oil	Pavers held in yard for at least one week.
Wash down components	Water pump	Haarup mixer Screw feed pipes Paving press	Electricity 36 kW	Slurry produced from wash down is first filtered then pressed to produce a waste cake that is left to dry naturally. 0.0021kg of waste cake is produced per tonne of product manufactured. Dried cake is eventually disposed as landfill, when a viable amount has been collected.
Load pavers onto delivery vehicle	Grab truck		Gas oil	Grab truck loads the required number of banded and wrapped paving product packs onto one of the company's flat backed delivery vehicles. Hydraulically operated hiab powered by the vehicles engine is used to facilitate the offloading process.

Table 1: Paving Product Manufacture to Factory Gate Energy Input Events.

Indirect energy usage

Indirect activity associated with the manufacture of the natural paving product took a number of forms including machinery maintenance and administration. Both elements were considered. The former by recording the number of site visits by maintenance personnel and determining their round trip distances and vehicle usage. The latter was the largest input and included such activities as processing payroll, personnel issues and orders and payments. These functions are carried out in a

separate head office. However, the head office carries out administration related to all of the products made by companies within the Manufacturers' group not just the natural concrete paving. It was therefore necessary to apportion administration energy use to that associated solely with the paving product being investigated. This was again carried out on a by-weight basis but this time it was based on the weight of the output of concrete paving from the Manufacturing Works to total weight of output from those other elements manufactured by the group administered from head office. It was found natural concrete paving output represented 1.52% of the group's total output. This percentage was used to calculate the proportion of the yearly gas and electricity consumption of the head office to associate with the natural concrete paving. The energy associated with the daily commute by staff employed at Head Office was determined by issuing a questionnaire to staff. This asked for details of commuting for example car share, public transport or own car. Where cars were used, actual round trip distances from home to work were specified and also make, model and engine capacity of vehicle. Fuel consumption figures were then obtained from individual motor manufacturers.

The preceding sections described how energy was identified and measured across the various contributors. The process of converting this to a CO_2 output was carried out using a series of excel workbooks to record fuel usage, determine the amount of this to be associated with the concrete paving, convert fuel to energy units, convert energy to a carbon dioxide output (based on the type of fuel) and finally aggregate the amounts of CO_2 together. Stages are described further below.

Energy to carbon conversion

A variety of energy sources were used by the stakeholders. Electricity use is directly recorded as an amount of energy in kilowatt hours by the utility meters. However, other fuels need to be converted into an amount of energy. This was achieved by multiplying the quantity of fuel used by its calorific value. The calorific values used in this project are provided by the Carbon Trust (2006) and shown in table 2.

Fuel	Calorific Value
Petrol	10.0 kWh/litre
LPG	7.4 kWh/litre
Gas/Diesel oil	10.8 kWh/litre
Fuel Oil	11.9 kWh/litre
Natural gas	11.0 kWh / m^3

Table 2: Calorific Values.

The amount of CO_2 released per kilowatt hour of energy consumed depends on the fuel type. Converting quantities of energy used to a CO_2 output was achieved by multiplying the amount of each form of energy used in kilowatt hours by a standard conversion factor in kilograms of CO_2 per kilowatt hour. The conversion factors used are provided by The Carbon Trust (2006) and are shown in Table 3.

Energy and Fuel Consumed		Emission Factor ($KgCO_2/kWh$)
Electricity from grid		0.43
Fuels		
Natural gas		0.19
Gas/diesel oil		0.25
Petrol		0.24
Heavy fuel oil		0.26
LPG		0.21

Table 3: Carbon Dioxide Emission Factors for Energy Related Emissions.

RESEARCH RESULTS

The main aim of the project was to determine the amount of carbon dioxide released as a result of the energy consumed to supply raw materials and manufacture a natural concrete paving product.

The embodied carbon content of natural concrete paving measured using the auditing boundaries of cradle to gate was found to be 0.166kg $kgCO_2/kg$. For the 450 x 450 x 50mm product this equates to a CO_2 output per unit area of 17.84kg CO_2/m^2

The embodied carbon content of the cement component measured up to the receipt of delivery at the Manufacturing Works was found to be 0.834kg CO_2 /kg

The embodied carbon content of the 150mm clean sandstone component measured up to receipt of delivery at the Manufacturing Works was found to be 0.0096kg CO_2/kg

The embodied carbon content of 5mm to dust limestone measured up to receipt of delivery at the Manufacturing Works was found to be 0.0067kg CO_2/kg

DISCUSSION

Values are necessary with which to compare the values of embodied carbon determined by this research project in order to highlight gross errors and make a comparison. The most widely used UK database of embodied carbon dioxide for building materials is the Inventory of Carbon and Energy (ICE) compiled by Hammond and Jones at the University of Bath (2008). The research results and ICE database values are shown in table 4. Before comparing these values it is worth comparing the values by the research for the processed and delivered limestone and sandstone. It is reassuring that whilst the embodied carbon value for sandstone is 43% larger than that for limestone that they are of a similar order of magnitude which is to be expected since they have similar energy input events associated with them. Both were extracted from a quarry, underwent crushing and finally were delivered to the Works by road transport.

Material	Research Results ($kgCO_2/kg$)	ICE Database Values ($kgCO_2/kg$)
Concrete Paving	0.166	0.127[6]
Cement	0.834	0.93[7]
Sandstone	0.0096	0.058[8]
Limestone	0.0067	0.087[9]

Table 4. Comparison of research results with ICE database values

Considering the comparative table the research value for concrete paving is larger than that found for precast concrete products in the database, whereas the values for cement, sandstone and limestone are all smaller. The research values for sandstone and limestone values stand out as being a much smaller than those in the database.

A number of explanations are possible for these differences.

- The ICE database calculates embodied carbon using a 'typical fuel mix in the relevant UK industry'. It could be that this fuel mix did not reflect the fuel mix found by this research.
- This research is for a specific set of operations whereas some industry generalisations appear in the database.
- There may have been some unknown inaccuracies in the research project.
- There may have been variations in handling for example differences in transport or crushing.

The research revealed a number of barriers to the accurate auditing of energy usage that could provide more consistent results. These are;

- Vehicle fuel consumption was not metered so it had to be estimated using average fuel consumption figures provided by logistics managers or from the vehicle manufacturer's published fuel consumption figures and distance travelled. Any variation in route travelled from the on-line route planner or fuel consumption (due to driving style or vehicle maintenance issues) would have led to an inaccurate estimate being made.
- The main production facility produced a range of concrete products. Apportioning overall energy use on a 'by-weight' of individual product output compared to total weight of output could lead to inaccuracies. It may, for example, be that different products use machinery differently and so the by-weight allocation of energy may not be appropriate.
- Some energy inputs were considered to make an insignificant contribution to the embodied carbon and so were not included, an example is commuting travel fuel usage of staff at raw material extracting sites.

The key suggestion for improving the accuracy of embodied carbon auditing is the introduction of extensive real time energy data acquisition. The technology for this already exists and would involve;

6 Based on the value for general concrete (0.1 kgCO2/kg) plus a modification factor for precast (prefabricated) concrete (0.027 kgCO2/kg)
7 Average CEM 1 Portland Cement
8 Stone sandstone
9 Stone limestone

- Installation of relevant energy monitoring equipment and software
- Vehicle telemetry to record fuel usage
- Sub metering of fixed and mobile plant associated with production lines

This data would need to be fed into a product batch database in real time and be aggregated to give a total. This would mean that as well as associating such items as quality assurance to a particular batch it would also be possible to state the energy consumed and hence CO_2 output produced during its manufacture.

CONCLUSION

The investigation carried out the main objective of measuring the embodied carbon content of concrete paving as manufactured and those of its main components. The second was to identify the barriers to the accurate auditing of energy use and hence CO_2 outputs. The embodied carbon results as found do show differences to values found elsewhere. The differences are likely to occur as embodied carbon measurement is still at an early stage and differences may arise in the range of energy input events and the auditing of these.

Standard auditing boundaries have been accepted, energy to CO_2 conversion factors have been agreed, however the outstanding issue preventing the accurate recording of CO_2 emissions for a particular batch of product remains that of real-time monitoring of energy usage along the production line. Sometimes this production line is discontinuous and so some method of accurately passing on energy use to proceeding stages would be needed. It is suggested therefore that further research should take place into the application of remote monitoring of energy consumption using multiple sub metering feeding data into a centralised data storage system.

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POTENTIAL USE OF THERMALLY DESORBED SOIL AS A PARTIAL CEMENT REPLACEMENT

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Keywords: Cement replacement, Concrete, Mortar, Soil remediation, Thermally desorbed soil.

ABSTRACT

The industrial heritage of the UK has given rise to around 100,000 sites, being classified as contaminated. There are many different techniques that have recently been developed to remediate land. Thermal desorption is one of these techniques. Contaminants in the soil are volatilised, which are then removed by a thermal or catalytic oxidiser. The chemical and physical properties of the 'burnt' soil', termed thermally desorbed soil (TDS), have significantly changed but is typically still disposed of to landfill.

The use of supplementary cementing materials has become a central aspect of construction economics and environmental preservation. This study therefore investigated the potential use of TDS as a partial cement replacement material. Cement was replaced from 0% (as the control) to 30% TDS in 10% increments. The compressive strength of the mortar cubes was then determined at intervals of 7, 28 and 91 days. For a direct comparison, a well-established pozzolanic material, fly ash (FA) was tested throughout the programme.

Strength was indirectly related to replacement level, with the control initially (up to 7 days) gaining, and thereafter retaining, the highest degree of strength. However, after 7 days the rate of gain in strength was higher for the replacement mixes (FA and TDS) than the control. There was no significant strength difference between the FA and TDS mixes up to 20% replacement. Hence, based on these initial strength results, the performance of TDS as a partial cement replacement (up to 20%) was directly equivalent to that of FA.

Environmental benefits for the use of TDS as a partial cement replacement would be twofold; firstly, by using a waste material rather than disposing to landfill; and secondly by using less cement. This would result in less carbon dioxide (CO_2) being released into the atmosphere during the cement manufacturing process, which is currently responsible for 7–10% of the global CO_2 emissions.

INTRODUCTION

The planning policy statement 23 (PPS23) for government policies on land affected by contamination gives guidance on the use of Brownfield[10] land for development. Many existing Brownfields are currently causing damage to the natural environment. Typically, this is from harmful pollutants leaching from the soil, which have been trapped from past industrial activity, into the surrounding watercourse. As such, it is paramount that these sites are remediated to prevent such an occurrence. A contaminant can be considered as a compound present in soil at higher concentrations than would be expected, and that has the potential to cause harm to the environment as a result of the concentration (Starkings and Cromie, 2007). Xenobiotics encompass all compounds that are foreign to living organisms. Such compounds may be released into the environment accidentally or due to negligence from industrial, agricultural or domestic usage (Alexander, 1999).

Contaminants are usually classified as organic or inorganic. Organic contaminants are those of biological origin. The inorganic contaminants are considered to be of non-living, non-biological origin (Holleman and Wiberg, 2001). Inorganic contaminants can be classified by the elements or groups they contain and include metals and non-metals (Madsen, 2003). They can also be attributed to petroleum, batteries, paint/wood preservatives, leaded petroleum and agricultural dips. Some inorganic contaminants such as sulphides, sulphates and cyanides generally arise as by-products from manufacturing industries (Sarsby, 2000). Figure 1.1 present examples of the most common contaminants found in soils. Sites contaminated with polycyclic aromatic hydrocarbons (PAHs) over a century ago are still routinely found to contain high levels of these contaminants despite long-term weathering and reduction processes.

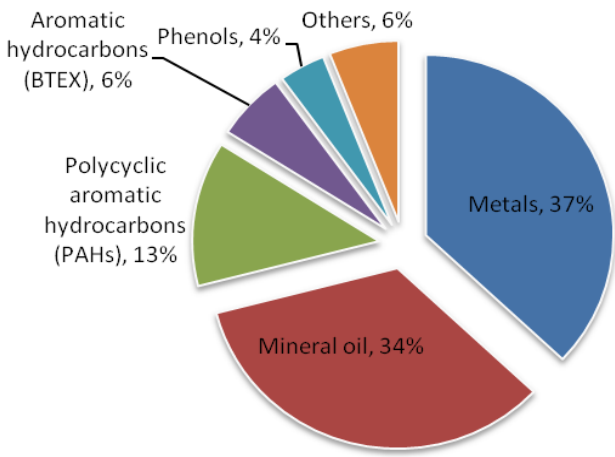

Figure 1.1: Overview of contaminant types

Remediation is initiated to guard human beings and their surroundings and allow the process of redevelopment to take place. Risk, in land contamination, results from three elements, namely: a

[10]The US Environmental Protection Agency gave in 1996 a definition of 'brownfield' as: "*…an abandoned, idle or underused industrial or commercial property where expansion or redevelopment is complicated by real or perceived environmental contamination*".

contaminant, pathway and receptor, as illustrated in Figure 1.2. Land is believed to be contaminated and requires remediation if the three elements of the pollutant linkage are in place. Remediation looks to remove one of these elements or break the linkage between these elements to prevent further pollution (harm) from occurring.

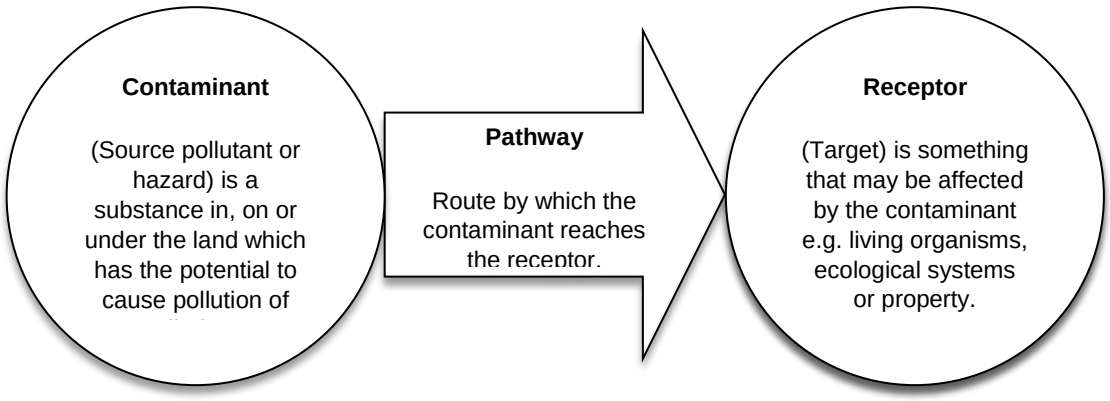

Figure 1.2: Pollutant linkage (Adapted from Environmental Protection Act, 1990)

In the UK the choice of a remediation process is influenced by cost-effectiveness, speed of reclamation and flexibility (Beckett and Cairnery, 1993). There are several technologies that can be employed for land remediation. They can be described as chemical, physical, solidification/stabilisation, thermal and biological. The technologies can be undertaken either *in-situ* or *ex-situ*. Table 1.1 shows the classification of the most common remediation options used in the UK.

Table 1.1: Main remediation technologies used in the UK (Nathanial *et al*., 2002)

Technology	Class	Application	Medium
Excavation & disposal	Civil Engineering	*Ex-situ*	Soil, water vapour
Pump and treat	Physical	*Ex-situ*	Water,
Air sparging	Physical	*In-situ*	Water
Soil washing	Physical	*Ex-situ*	Soil
Soil vapour extraction	Physical	*In-situ*	Soil
Windrows	Biological	*Ex-situ*	Soil
Biopiles	Biological	*Ex-situ*	Soil
Thermal desorption	Thermal	*Ex-situ*	Soil
Vitrification	Thermal	*In-situ*	Soil
Incineration	Thermal	*Ex-situ*	Water vapour
Capping	Civil Engineering	*In-situ*	Soil
Vertical barriers	Civil Engineering	*In-situ*	Water, vapour
Bioslurping	Biological	*In-situ*	Water
Biosparging	Biological	*In-situ*	Water
Oxidation	Chemical	*In-situ*	Soil
Reduction	Chemical	*In-situ*	Soil
Natural attenuation	Biological/Chemical/Physical	*In-situ*	Water

Thermal desorption is a technique that uses direct or indirect heat to destroy contaminants by exposing the contaminated media to high temperatures (Bouwer and Zehnder, 1993). This process uses burners to provide heat to deplete the levels of contaminates within the soil. Contaminants are heated to temperatures ranging between 500 and 650 °C to volatilize and separate them from the soil.

The vaporised contaminants are then passed through a vapour system to destroy the contaminated gases before they are emitted into the atmosphere, as illustrated in Figure 1.3. Heat can be applied by radiation or by convection from direct contact with combustion gases and can also be indirectly applied by heating the outside of the cylinder (TR-2090-ENV, 1998). It is a proven sustainable technology and has a firmly defined outcome for both organic and inorganic contaminants (Starkings and Cromie, 2007). Thermal desorption is considered to be an appropriate solution for sites where a complex array of contamination is present, such as gasworks and chemical plants. The thermal process changes the structure of the soil matrix by destroying the organic compounds, leaving a residual soil with a consistency of ash (Allen, 2009). The resultant remediated soil is either disposed of to landfill or used as a fill material, depending on how successful the remediation process has been.

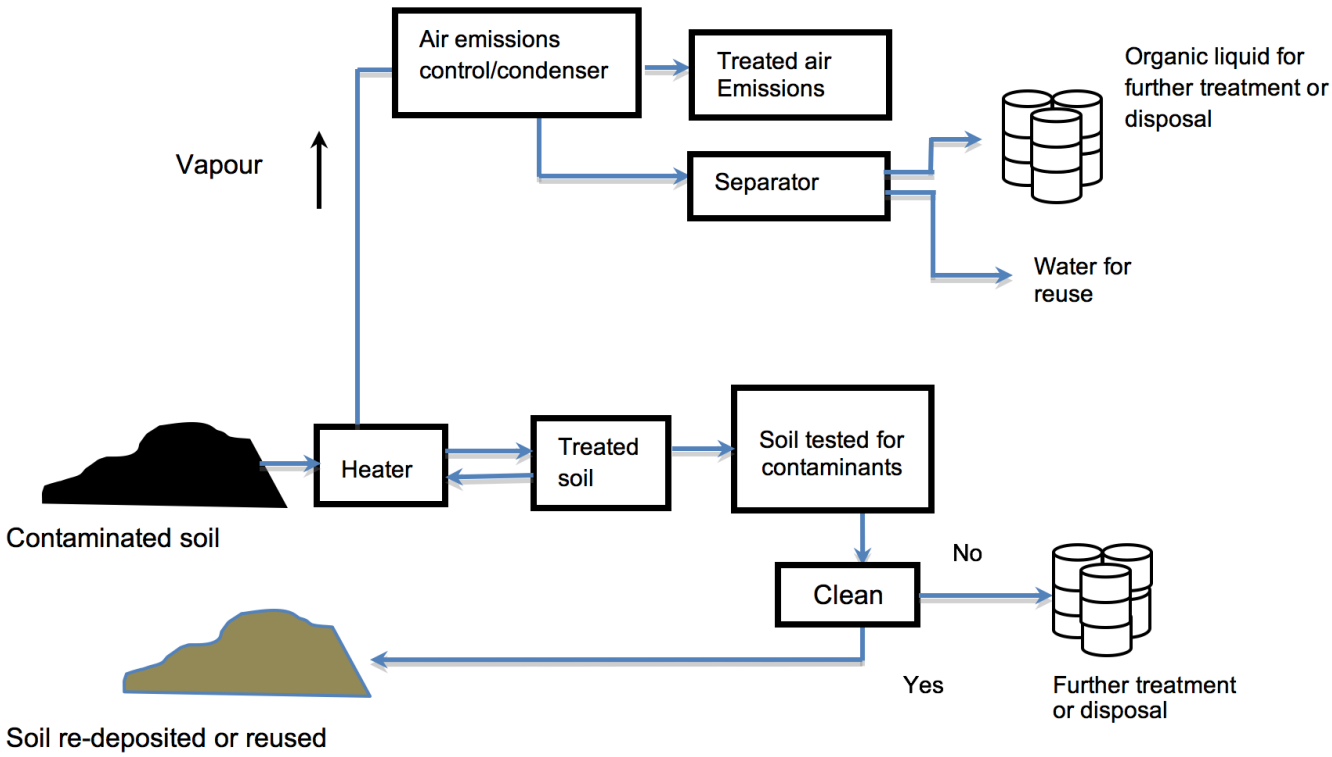

Figure 1.3: Thermal desorption process (EPA, 2004)

When used as fill material, the *in-situ* strength property of the TDS has been noted to increase with respect to time, hence indicating some form of cementitious or pozzolanic action naturally emanating from the burnt soil. Thus, the research work detailed in this paper considers the potential use of TDS as a partial cement replacement. The advantages being the reuse of a waste material together with a reduction in the amount of cement required. The resulting outcomes being a saving in landfill space and cost, together with a reduction in CO_2 emissions from manufacturing less cement.

LITERATURE REVIEW

The literature review is presented in two main sections. The first section contains a general information on cement and the second section concentrates on pozzolans, in particular FA.

Cement

Cement is a material with adhesive and cohesive properties capable of bonding mineral fragments (sand, bricks, stone, etc.) together. It is capable of reacting with water to give a hard strong mass. The main cement constituents are calcium carbonate (from chalk or limestone); silica and alumina (both from clay/shale). Cement is manufactured by heating limestone and clay together to form clinker rich in calcium silicates. This is ground to fine powder with a small proportion of gypsum (calcium sulphates), which controls the rate of setting when the cement is mixed with water.

Table 2.1 gives an analysis of the sources of CO_2 emissions associated with cement manufacture. One of the main ways to reduce CO_2 emissions, is to reduce the amount of cement manufactured by blending it with other binding materials, such as pozzolans. Table 2.2 demonstrate the range of blended cements used in the UK.

Table 2.1: CO_2 emissions associated with the production of one tonne of PC (Adapted from: ICT, 2007)

Source	Indicative CO_2 emitted (kg)	Comment
Chemical decomposition (breakdown of limestone)	800–900	The major source of CO_2 is intrinsically unavoidable
Fuel	350	Use of waste as fuel can benefit sustainability
Electricity	80	The CO_2 is normally emitted off-site at a power station
Total	1,330	

Table 2.2 Cement types and clinker ratio (Price, 2009)

Cement type	Second main constituent	Minimum clinker (%)	Maximum cement/clinker
CEMI	_	95	1.05
CEM II/A-S	Slag	80	1.25
CEM II/B-S	Slag	65	1.54
CEM II/A-V	Fly ash	80	1.25
CEM II/B-V	Fly ash	65	1.54
CEM II/A-L	Limestone	80	1.25
CEM II/A-D	Silica fume	90	1.11
CEM IV/B	Fly ash	64	1.56
CEM III/A	Slag	64	1.56
CEM III/B	Slag	20	5.00

Pozzolans

The term pozzolan refers to materials that react with calcium hydroxide (CH), in the presence of water, to form hydrated products with binding properties (Massazza and Costa, 1979). Natural pozzolans include volcanic ash, diatomaceous earth, metakaolin (calcined clay) and opaline shade. Artificial pozzolans include FA – also known as pulverized fuel ash (PFA), brick dust, calcined kaolin, rice husk ash (RHA), silica fume, ground granulated blast furnace slag (GGBS or slag) and certain types of metallurgical slags. Pozzolans comprise of silica in a reactive state, being in the form of siliceous and aluminous materials.

FA is one of the most commonly used pozzolans. It is a coal by-product generated by the combustion process that occurs in coal-fired plants. Coal is ground and blown with air into a combustion chamber where it instantaneously burns, producing heat and creating a molten mineral residue (Roy *et al.,* 1981). After cooling the molten residue hardens and becomes ash. The ash is a complex material consisting of powdery spherical particles that are a heterogeneous combination of amorphous and crystalline phases (Karim *et al*., 2011). FA consists of crystalline minerals (namely: quartz, mullite, cristobalite, magnetite, maghmite and hematite) and non-crystalline (amorphous) glass (Ward and French, 2005).

Interest in the use of FA as a cement replacement began in the late 1940s. FA was selected for use in the construction of the Lednock, Clatworthy and Lubreoch dams in Scotland, UK (Allen, 1959). For example, the construction of Lednock dam involved 62,500 m^3 of concrete and the use of FA saved 3,000 tons of PC.

About 10,000 million tonnes of FA is produced in the UK every year and half of this amount is used in the construction industry (Khatib, 2009). The utilisation of FA is due to environmental, economic and technical considerations (Fu *et al*., 2002; Worrell *et al*., 2000). Environmentally, the use of FA as a pozzolanic material in the manufacture of cement, contributes to the reduction of about 25 million tonnes of CO_2 emissions per annum (Ahmaruzzaman, 2010). Economically, the utilisation of the FA has the following financial returns (Environmental Agency, 2010):

- It saves the power industry £5 million each year, largely due to the reduction in landfill charges which would be associated with its disposal.
- It creates markets (as illustrated in Fig. 2.1) worth over £8.5 million a year.

Also in respect to technical consideration research has shown that the use of FA has a large number of positive effects (including factors such as workability, drying shrinkage and durability) on the fresh and hardened states of mortar/concrete.

Summary of literature

In order to confront the problems of climate change it is imperative that CO_2 emissions from the cement industry are reduced and waste streams are minimised. Partially replacing cement with a pozzolanic material (such as FA) to form a blended cement is a very positive development in the cement industry's efforts to achieve sustainability.

The rest of this paper is directed towards investigating the potential use of TDS as a partial cement replacement as a new pozzolanic (or cementitious) material. Throughout the testing programme FA was tested alongside TDS so that a direct comparison could be made with that of a well-established pozzolan.

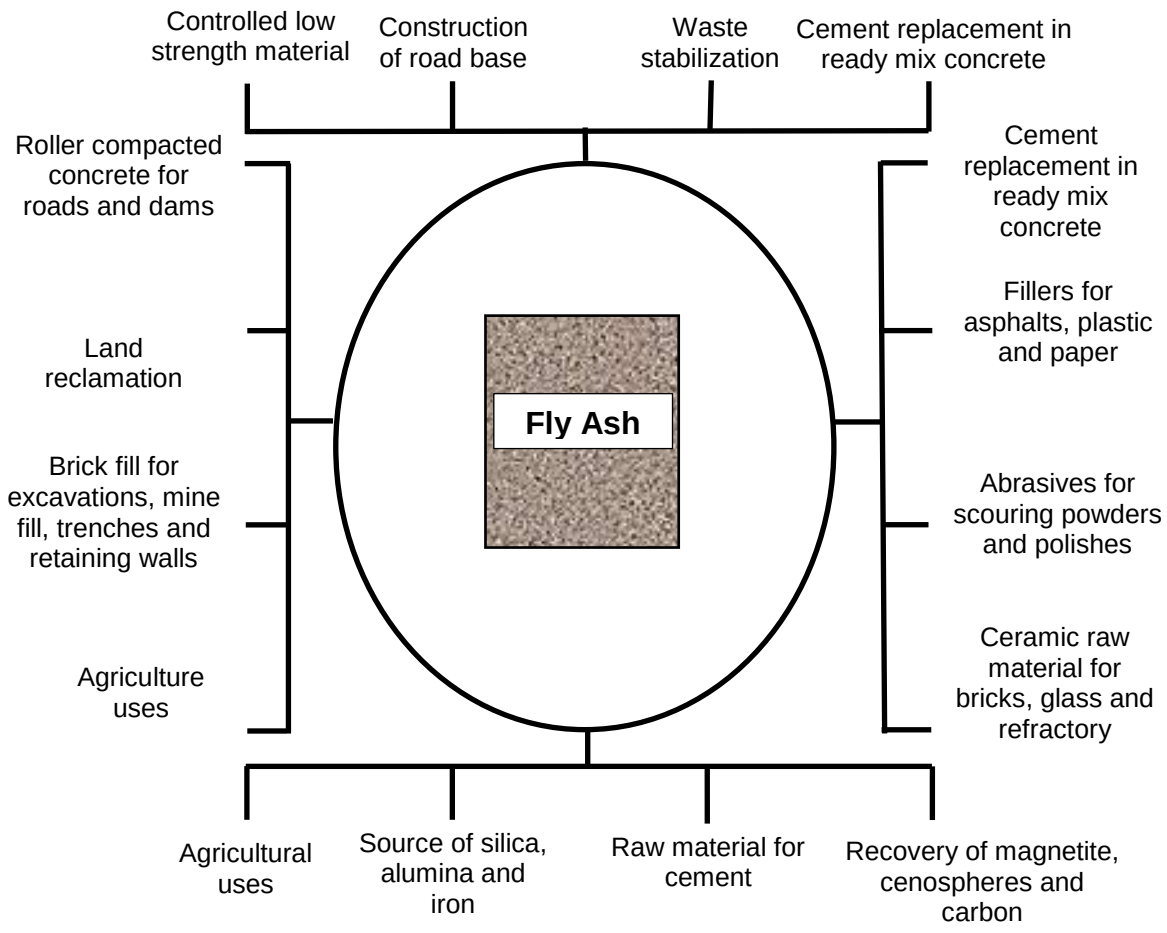

Figure 2.1 Possible use of FA based on properties (Adapted from Wang and Wu, 2004)

MATERIALS

The TDS used in this research programme was sourced from the former Avenue Coking Works Site. The Avenue Site is located in Chesterfield, Derbyshire, UK – National Grid Ref 438994,367888. The general solid geology of the area is composed of Middle and Lower Carboniferous coal measure, which consists of inter-bedded mudstone, siltstone, sand stone, shale and coals (EMDA, 2001). The site is 98 hectares and was used for 36 years for coking and chemical works. At full capacity the coking works employed 800 staff and carbonised 2,175 tonnes of coal a day; producing approximately 1,400 tonnes of smokeless fuel, 65 tonnes of sulphuric acid, 35 tonnes of ammonium sulphate, 250 tonnes of tar and 20,000 gallons of crude benzole. Prior to the coking and chemical works, it was used as a coal mining and iron works site. It also received waste from other National Coal Board sites in the region. It is a prominent site within the region and also nationally within the remediation sector as it was dubbed, in the late 1990s, as one of the most contaminated sites in Europe. The site is contaminated with a complex array of chemicals, such as sulphates, creosote, blended fuel wastes, benzol, tars, asbestos and spent oxides.

The complex myriad of contamination and the inconsistent underlying ground conditions on site gave an indication that there was no single treatment technology that was able to remediate the soil. The remediation trial programme in 2001 was based on the use of many techniques to assess the most suitable technologies. In October, 2010 the Avenue Site commenced its full remediation works. The majority of the soil (300,000m^3) was treated by thermal desorption, followed by bioremediation (75,000m^3) and soil washing (50,000m^3). It was the soil from the thermal desorption plant that was used in this research investigation. The soil was double bagged using shovels and the tops loosely tied using tie wraps. The bags were then transported to Leeds Beckett University and kept cool and in the dark in accordance with BS7755-2.6 (1994).

The other constituents of the mix consisted of a common base of PC, general purpose sand, hydrated (HL2 building) lime and tap drinking water. The type of PC used in this testing programme was Procem CEM I 52.5N from Lafarge Cement. It also has consistent strength conforming to the BS EN 197-1 (2000) requirements. The FA was supplied by Drax Power Station, North Yorkshire, UK.

RESEARCH METHOD

A laboratory based experimental programme was undertaken to evaluate the effects of partially replacing cement in mortar with TDS (and FA). Preparation and storage of the specimens was carried out in accordance with BS EN 1015-11 (1999). The percentage of cement replacement with TDS (and FA) ranged from 0–30% in increments of 10% by weight. Replacement by weight rather than by volume is favoured as it provides better accuracy and avoids bulking problems (The Concrete Centre, 2011). For control purposes a control mix with 100% PC mortar (i.e. 0% cement replacement) was used throughout the testing programme. Each mix was repeated three times to ensure replicability.

Mortar samples were prepared at room temperature. The water/binder (w/b) ratio of 0.6 was established from trial mixes based on the texture of the materials and the volume of the mix, as well as the workability of the mortar. The w/b ratio was constant for all the mixes. The sand/binder ratio (s/b), by weight, was equal to 10.6 and was maintained constant throughout the experiment.

RESULTS

Figure 5.1(a–b) shows the mean performance of the 10, 20 and 30% FA and TDS mortar cube samples at set curing durations. The dashed line of the figure represents the minimum strength requirement of 4 N/mm^2 as specified by BS EN1996-1-1 (2005) for category (iii) masonry mortars.

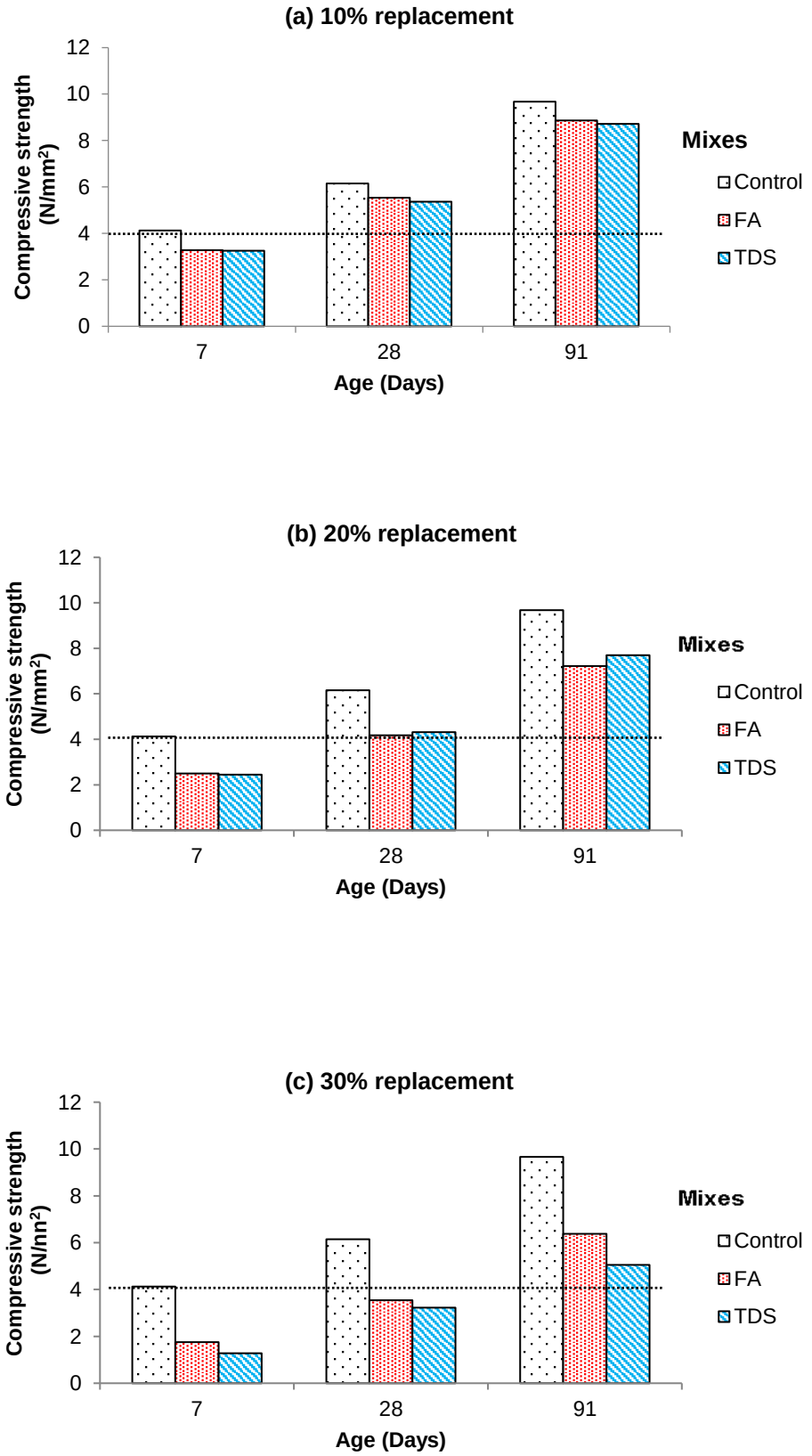

Figure 5.1 Replacement mortars vs control

The rate in compressive strength gain for the control and cement replacement mixes (both FA and TDS) from 7 to 28 days and 28 to 91 days is shown in Figure 5.2.

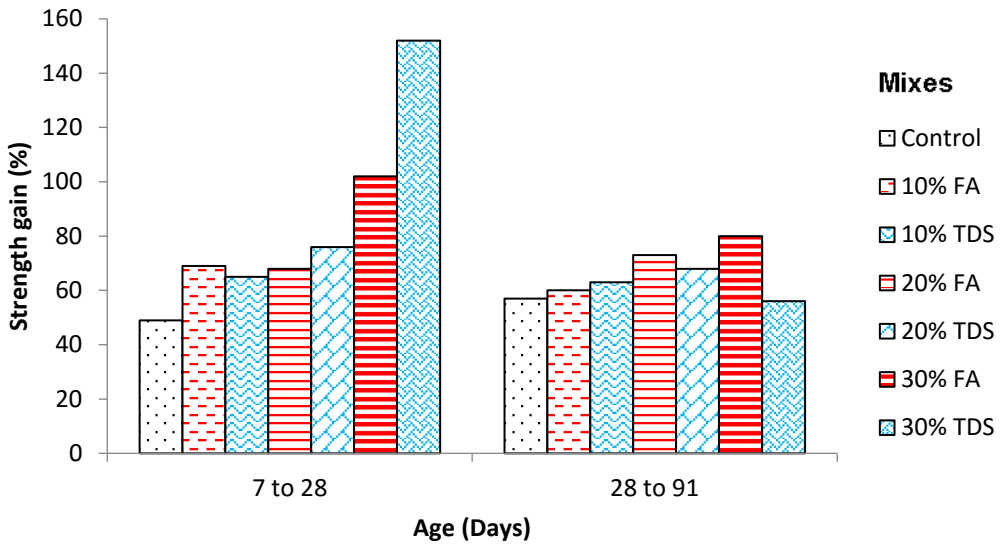

Figure 5.2: Compressive strength gain

DISCUSSION

From Figure 5.1 it can be seen that the strength of the replacement mixes trailed the strength of the control. The strength was indirectly related to replacement level, i.e. as replacement material increased less strength was obtained. At 10% replacement, there were no significant difference between the strength of the TDS and FA. At 20%, TDS and FA samples were again directly comparable up to 28 days; thereafter, TDS gained slightly more strength, being 6.5% stronger at 91 days than FA. However, at 30% replacement the inverse was true, with FA being slightly stronger than TDS.

At 7 days the mean strength of the control was 4.13 N/mm^2, which just met the minimum strength requirement of 4 N/mm^2 (dashed lines on Fig. 5.1). However, none of the replacement samples (TDS and FA) met this requirement at 7 days. The strength of the 10 and 20% replacement samples was just over 5 N/mm^2 at 28 days, which now met the minimum requirement. At 30% replacement both TDS and FA failed to meet the specified 4 N/mm^2 at 28 days but exceed this minimum value at 91 days.

Up to 7 days the control had the greatest rate of strength gain; the trend then followed replacement level. This would be expected as the pozzolanic action of the replacement mixes would not be evident until after this timescale (Neville, 2011). Between 7 and 28 days all the TDS and FA replacement mixes (10–30%) had a higher strength gain over that of the control (Fig. 5.2). This was particularly true for the 30% replacement mixes, which was probably due to the higher percentage of pozzolanic material. This confirms data published by previous researchers (e.g. Atis *et al.,* 2003; Chindaprasit *et al*., 2004) who also observed that the pozzolanic reaction is more apparent from 7 days. The actual strength, however, remained lower than the control.

Between 28 and 91 days, apart from the TDS at 30%, the replacement mixes had higher strength gains than the control (Fig. 5.2). Normally the strength of the control mix reaches a plateau from

around 28 days. For the 10% replacement samples the TDS and FA mixes had comparable strength gains around 60%. At 20% replacement level the strength gains were again similar being around 70% for both replacement materials. However, at 30% replacement the FA mix had superior strength gains to the TDS mix, which does not fit the recognised trend, hence further testing would be required for confirmation.

In general, the higher the amount of replacement material the greater the strength gain after 7 days. However, overall the strength is somewhat compromised by the initial strength (up to 7 days) being indirectly proportional to replacement level. In practice, pozzolanic materials strength gains are noticeable between 7 and 28 days (Kiattikomol *et al*., 2001; Chindaprasirt *et al.*, 2004). It was found that the TDS samples performed in this way. Up to 20% replacement the TDS samples directly matched the compressive strength of the FA samples when cured up to 91 days.

CONCLUSIONS & FURTHER WORK

TDS and FA mortars exhibited inferior compressive strength to the control PC mortar at 7, 28 and 91 days of curing. Up to 20% replacement level there was no real strength differential to report between TDS and FA – both meeting the strength requirement of category (iii) mortars at 28 days. However, at 30% replacement level TDS strength lagged behind FA.

The improved TDS properties could be attributed to the burning of the original geological materials (clay and shale). Also, the heating of contaminates such as lime solids, burnt shale, clay, clinker and lime waste contributed to the cementitious properties of the soil.

The use of TDS as a partial cement replacement would reduce the embodied CO_2 in a mortar mix. For example, if 20% cement is replaced this would result in the reduction of about 188 kg of CO_2 per tonne of PC not being released into the atmosphere. Also, there will be a cost saving to be gained in terms of the reuse of TDS, i.e. not disposing it as a waste material.

Data will soon be published to demonstrate the:

- Long-term strength of TDS mortar samples, i.e. up to 654 days.
- Influence TDS fineness has on the overall strength and workability.
- Flexural strength of TDS mortar samples.
- Drying shrinkage of TDS mortar samples.
- Durability of TDS mortar samples in respect to freeze/thaw damage and sulphate resistance.
- Chemical and mineralogy profiles of TDS by X-ray diffraction (XRD) and X-ray fluorescence (XRF) respectively.
- Potential use of TDS in concrete.

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Planning and Sustainability

EXPLORING THE VALUE OF URBAN TREES AND GREEN SPACES IN LEEDS, UK

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ABSTRACT

In 2014, around 54% of the world's population were living in towns and cities, and this number is projected to increase to nearly 70% by the middle of the century. Almost two thirds of the urban area that will exist by the year 2030 is yet to be built, so it is vital that we take the opportunity to create and maintain healthy and sustainable urban environments.

Urban green spaces such as domestic gardens, parks and woodlands provide a multitude of benefits to human urban populations, and a vital habitat for wildlife. By improving physical fitness and reducing depression, the presence of green spaces can enhance the health and wellbeing of people living and working in cities. Green spaces also indirectly impact our health by improving air quality and limiting the impact of heatwaves by reducing urban temperatures. In addition, urban vegetation stores carbon, helping to mitigate climate change, and reduces the likelihood of flooding by storing excess rain water.

We will present an overview of the existing literature around the impacts of green spaces in urban populations and describe the Leeds Forest Observatory (LFO), an outdoor laboratory being established in collaboration with Leeds City Council.

We will also outline our plans to assess the local and city-wide woodland resource using the i-Tree software, designed to facilitate economic valuation of urban trees through their role in carbon storage, air quality control and flood reduction.

INTRODUCTION

Here we present an overview of the peer-reviewed academic literature and policy reports around the impacts of urban green space. Additionally, we will outline our plans to build on this research in order to understand the impacts of parks and green spaces in the city of Leeds.

Health & wellbeing

Access to green space improves our mental wellbeing (White et al., 2013), reducing the need to treat for anxiety and mental health conditions (Nutsford et al., 2013). Depressive disorders are now the foremost cause of disability in middle- and high-income countries (World Health Organisation, 2008) and can be precursors for chronic physical health problems.

Spending time in green spaces has been shown to produce levels and patterns of chemicals in the brain associated with low stress (Ward Thompson et al., 2012) and positive impacts on blood pressure (Hartig et al., 2003). Positive links have also been demonstrated between how well people perform at attention-demanding tasks and time spent, either beforehand or during, in green space (Hartig et al., 1991, Tennessen and Cimprich, 1995, Hartig et al., 2003, Roe and Aspinall, 2011).

Across Europe, approximately 1 in every 15 deaths is associated with a lack of physical activity (Ekelund et al., 2015). In the UK, only one third of the population achieves the recommended level of exercise (Department of Health, 2011) and the impact of this on our health is estimated to have a direct economic cost of £1 billion per year (Scarborough et al., 2011).

Green areas encourage physical activity by providing a pleasant environment in which to exercise (Coombes et al., 2010); linear woodland trails encourage walking and cycling, whilst large sport and community parks encourage more formal physical activity (Brown et al., 2014).

Where green space is available, the socioeconomic position of the local population does not affect how frequently it is used (Grahn and Stigsdotter, 2003), implying that where accessible green space is provided it will be used and may help to reduce socioeconomic health inequalities (Mitchell and Popham, 2008, Mitchell et al., 2015).

Urban green spaces provide pleasant areas to relax and socialise, promoting greater levels of social activity and stronger neighbourhood relationships (Sullivan et al., 2004). This can be particularly important in maintaining a high quality of life for elderly people (Kweon et al., 1998, Sugiyama and Ward Thompson, 2007, Sugiyama et al., 2009).

To maximise these benefits, green space should be as accessible as possible since people are more likely to visit green space if they do not have to travel far to reach it, and the most frequent visitors report the greatest benefits to their mental well-being (Dallimer et al., 2014a).

Temperature & climate change

In the UK, urban temperatures are typically 1-2°C higher than the surrounding rural areas (Watkins et al., 2002, Jones and Lister, 2009). This urban heat island (UHI) effect occurs because the materials used to build towns and cities absorb more of the sun's energy than the natural surfaces they replaced.

The UHI effect makes people living in urban areas particularly vulnerable to heat waves, for example there was an estimated 42% increase in mortality in London during the heatwave that affected Europe in August 2003 (Johnson et al., 2005).

Urban green spaces reduce the UHI effect by providing shade and by cooling the air through the process of *evapotranspiration*. During evapotranspiration, the sun's energy is used to transfer water from the leaves of plants into the atmosphere (Grimmond and Oke, 1991).
Urban green spaces are on average around 1°C cooler, during both the day and night time, than built-up regions in the same town or city (Bowler et al., 2010), and this cooling effect can extend beyond the green space itself, into the surrounding urban areas (Yu and Hien, 2006). During the summer this may reduce the need for air conditioning, and associated energy use, in nearby buildings(McHale et al., 2007). Large parks containing many trees with wide canopies, and minimal paving, reduce the urban heat island effect the most (Sani, 1990, Potchter et al., 2006, Chang et al., 2007, Bowler et al., 2010).
The amount of carbon dioxide in the atmosphere has increased by more than 40% since humans began industrialising, resulting in a gradual warming of the planet over the past century (IPCC, 2013). Trees and plants take carbon dioxide from the atmosphere and around half of it is stored in their branches and roots, with large amounts of carbon also stored by the surrounding soils.
This process is known as *carbon sequestration* and, as long as the vegetation is preserved, results in an overall reduction of atmospheric carbon dioxide concentrations. However, the decomposition of dead trees and plants returns carbon dioxide to the atmosphere. Understanding the carbon balance of any green space therefore requires an analysis of the relative amounts of sequestration and decomposition, in addition to any maintenance related greenhouse gas emissions (e.g., through mowing, irrigation and the use of fertiliser).
Overall, urban green spaces take in more carbon than they return to the atmosphere (Nowak and Crane, 2002, Nowak et al., 2013) but their design and maintenance play a crucial role in determining how much carbon they will store. For example, a "forest-like" green space with many trees and native vegetation ground cover maximises carbon sequestration over a "park-like" design with fewer trees and frequently mown grass (Strohbach et al., 2012). As well as creating new green space, looking after existing mature trees is particularly important because they continue to sequester and store large amounts of carbon (Stephenson et al., 2014). Woodland areas that are managed to minimise tree mortality, and do not require intensive irrigation or fertiliser use, will maximise carbon sequestration (Jo and McPherson, 1995, Strohbach et al., 2012).

Air quality

Urban air pollution consists of tiny particles, known as particulate matter (PM), and gases such as ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). These pollutants are formed mainly as a result of vehicle and industrial emissions.
Poor air quality is a serious threat to human health, causing problems for the respiratory system and cardiovascular diseases (Pope et al., 1995, Pope et al., 2002). In many UK cities, including Leeds, average levels of NO_2 in the air exceed the legally binding limits set by the European Union (European Commission, 2008).
Worldwide it is estimated that approximately 3.7 million deaths per year are caused by exposure to poor ambient air quality (World Health Organisation, 2014). At the local scale, exposure to particulate air pollution is estimated to cause 350 premature deaths annually in Leeds, and 29,000 across the whole UK (Public Health England, 2014).
Trees and shrubs have multiple impacts on air quality. They can improve air quality by removing both particles and gases from the air; particles stick to the surface of the leaves, and gases are taken up through pores on the leaf surface. Trees with complex, ridged or hairy leaves (such as pines) tend to capture more particles than trees with broader, smoother leaves (Beckett et al., 2000, Freer-Smith

et al., 2005, Räsänen et al., 2013). However, plants also emit volatile organic gases (Owen et al., 2003) into the atmosphere that can result in the formation of O_3 and PM under certain conditions (Chameides et al., 1988, Donovan et al., 2005, Curci et al., 2009, Sartelet et al., 2012).
In places, trees may exacerbate local pollution by reducing the ventilation of air. The presence of large trees in narrow street canyons can obstruct wind flow and limit the ability of trees to remove pollutants (Buccolieri et al., 2009, Vos et al., 2013). As a result, planting hedges (Wania et al., 2012) or adding "green walls" (Pugh et al., 2012) in polluted street canyons may be more beneficial.
Current understanding suggests that the presence of urban vegetation results in an overall reduction in air pollution (Nowak et al., 2000, Nowak et al., 2006). For example, schools surrounded by green space have been shown to experience lower levels of traffic-related pollution in their classrooms (Dadvand et al., 2015). However, more research is required to fully understand the multiple ways in which urban vegetation can affect air quality.

Flooding & water quality

In urban areas, the impermeable materials used for roads and pavements mean that rain is not absorbed and remains on the surface (Pauleit and Duhme, 2000). During periods of heavy rainfall this water accumulates and when the drainage capacity of the area is exceeded, flooding will occur.
In contrast, vegetated surfaces are able to intercept (Asadian and Weiler, 2009) and store water (Sanders, 1986), reducing the volume of rainwater run-off. Benefits from individual trees are maximised if they are planted in tree pits containing permeable soils able to absorb additional water (Armson et al., 2013), or structural soils that facilitate the growth of tree roots beneath pavements and roads (Bartens et al., 2008).
A further consequence of high levels of surface water run-off is that rainwater washes pollutants away from the surfaces it falls onto, transporting them into water courses (Ellis, 1991). This can be detrimental to water quality in streams, rivers and lakes and lead to high pollutant loading at water treatment facilities (Characklis and Wiesner, 1997).
In the UK, climate change is likely to lead to wetter winters (Jenkins et al., 2009) which would exacerbate existing flooding and water quality issues. Including green spaces as part of new urban developments, as well as integrating them within existing urban regions, could help to reduce these risks (Ellis et al., 2002, Villarreal et al., 2004, Gill et al., 2007) and offers an alternative to other hard engineering flood control that can be disruptive and expensive to install.

Wildlife & Habitats

Our towns and cities are typically considered to host a less diverse range of plants, animals and birds than nearby rural areas (McKinney, 2006). However, green spaces within an urban area can be home to many of the same species that are more commonly associated with rural settings (Cornelis and Hermy, 2004), including those that are rare or threatened (Schwartz et al., 2002, Fuller et al., 2009). For some species, urban areas can provide a more favourable habitat than intensively farmed countryside (Fuller et al., 2009, Baldock et al., 2015), suggesting that towns and cities could make an important contribution to national conservation efforts.
Large parks and woodland regions are able to support the widest range of species (Cornelis and Hermy, 2004), but even small areas of vegetation such as roundabouts (Helden and Leather, 2004), roadside verges (Saarinen et al., 2005) and green roofs (Baumann, 2006, Brenneisen, 2006) can support a range of plants, insects and birds.

For many city dwellers, spending time in urban green spaces is their only regular opportunity to be surrounded by nature. Research suggests that people get more enjoyment from spending time in green space when they perceive there to be a high level of biodiversity (Dallimer et al., 2012) and that visitors to green spaces would be willing to pay to see an enhancement in the species richness of plants, birds and invertebrates (Dallimer et al., 2014b).

Urban green spaces can act as "wildlife corridors", linking together larger parks, and providing links to rural areas on the outskirts of towns and cities. This facilitates the movement of animals, birds and insects between individual green spaces and prevents the fragmentation and isolation of wildlife (Hale et al., 2012, Rouquette et al., 2013).

In the UK, urban green spaces form an important habitat for pollinators, such as bees, butterflies and hoverflies (Baldock et al., 2015). Maintaining a healthy population of pollinators is vitally important as many flowers and crops (including tomatoes, apples and strawberries) depend upon them in order to reproduce. Pollinator populations are declining in the UK (Goulson et al., 2008, Potts et al., 2010), so the provision of viable habitats in urban regions could form part of a broader strategy to combat this trend.

The more green space the better for urban wildlife, but strategies designed to enhance biodiversity will depend on the location, type of habitat and species present (Commission for Architecture and the Built Environment, 2006). However, some general themes emerge, such as: less intensive management practices, e.g., infrequent mowing of grass; protecting some parts of the green space from human interference, e.g., routing paths away from the most suitable nesting locations to prevent adverse effects on the reproductive success of birds; and the introduction of locally native wildflowers (Commission for Architecture and the Built Environment, 2006).

Economic impacts

The presence of green space affects an urban region in the many different ways described in this document; the economic impacts of which are not straightforward to quantify and estimates can vary widely (Saraev, 2012). In terms of direct financial impacts, case studies from around the UK suggest that proximity to green space is positively linked to both commercial and residential property prices, with properties overlooking a park being valued around 5-7% higher than equivalent properties elsewhere (Commission for Architecture and the Built Environment, 2005). The creation, maintenance and management of green space also generates employment opportunities, and may have indirect benefits to local economies by encouraging further investment and property development in the area (Saraev, 2012).

An assessment conducted for the Mersey Forest, a tree planting programme that now forms a 1300 km^2 network of woodlands and green spaces across Cheshire and Merseyside, concluded that every £1 invested in the programme was more than doubled (Regeneris, 2009). This was due mostly to tourism expenditure, the creation of forestry related jobs, estimated social cost savings (such as the impact of reduced air pollution), and well-being benefits (such as people's perception of increased biodiversity and improved visual quality of the environment). The assessment concluded that the location of green space is key; to maximise the benefits, green space must be easily accessible to both local people and tourists, or at least viewable from their homes or while travelling.

However, it is not clear whether the assignment of monetary values can fully capture the importance of non-monetary effects, such as increased biodiversity or the cultural significance of a woodland. Further research is required to develop metrics that can appropriately combine monetary and non-monetary valuations in order to assess the true value of urban green spaces.

Planned Research

Through a collaboration between the University of Leeds, the United Bank of Carbon and Leeds City Council, we will establish the Leeds Forest Observatory (LFO) in Middleton Park, Leeds. The LFO will allow long-term scientific monitoring of a specific patch of semi-natural ancient woodland, along with the collection of data relating to the park as a whole.

By intensively monitoring this woodland over time, we will be able to explore the role of the forest in carbon sequestration, influencing air quality, remediation of the urban heat island effect and other ecosystem services. We will also collect data relating to public use of the park and how various characteristics (e.g., level of biodiversity, access to cycle paths) may influence the level of use the park experiences.

Additionally we will be able to quantify the economic value associated with several of these ecosystem services, both locally and at the city level, using the innovative i-Tree software (USDA Forest Service). i-Tree combines online meteorological and air quality data with information collected about a regions trees (i.e., number, size and species) to determine the impact on carbon sequestration, air quality and flood alleviation.

DISCUSSION AND CONCLUSIONS

Green spaces and woodlands have a wide range of impacts on urban communities. The value of these impacts, or ecosystem services, is difficult to quantify and therefore challenging to compare to other land-uses that may generate revenue in a more traditional manner. Through the establishment of the Leeds Forest Observatory and wider investigations, we aim to better understand the true value of urban woodlands to the city of Leeds.

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Social Value, Health, Safety and Wellbeing

OCCUPATIONAL SAFETY AND HEALTH (OSH) SUSTAINABILITY COMPLIANCE IN THE GHANAIAN CONSTRUCTION INDUSTRY: PERSPECTIVE OF CASUAL WORKERS

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ABSTRACT

Health and safety sustainability is fundamental to the performance and growth of the construction industry as well as all other economic sectors globally. OSH offers a risk free and safe working environment with influence on productivity and as such it's imperative for construction firms to provide and ensure compliance by all workers, particularly casual workers. The study sought to find out the perspective of casual workers on the compliance to occupational health and safety (OHS) practice in the Ghanaian construction industry, as well as sustainable OSH strategies to improve the compliance level of casual workers. A structured interview questionnaire survey was used to collect data from casual workers on selected construction sites in Ghana. The study revealed a poor compliance to basic OHS regulations by casual workers. This was attributed to; unsafe attitudes and behaviour, less education on health and safety, inadequate supply of personal protective equipment, less supervision and improper use of tools and equipment. Recommendation are made for the empowerment of the factories inspectorate and labour departments to effectively undertake their mandate under the law, the merger of all occupational safety and health policy documents into one single document is recommended and finally the passage of the construction industry bill to help regulate ensure strict compliance by industry players in the implementation of projects. In conclusion, strict compliance to OHS practice of casual workers should be ensured through close supervision at site; thus wearing a PPE must be a pre-requisite to access to site, safety education for workers should be undertaken as well as ensuring that occupational safety and health safety compliance declaration be considered a basic contractual requirement for the award of projects (at least for government of Ghana funded projects).

INTRODUCTION

According to Taubitz (2010), Health and safety sustainability (HSS) resonates similar objectives of maximizing and making good use of both social, economic and environmental resources of a project. Sustained health and safety practices are fundamental to the performance and growth of the construction industry globally. The adverse occurrence of occupational safety and health is widely reported in all sectors of Ghana's economy, thus galamsey sites (illegal mining activities), transport business, timber operating firms, farming and heavy cutting machines, milling industries and the constructions industry (Dwomoh, G., Owusu, E.E. and Addo, M., 2013). Occupational Safety and Health (OSH) measures offers a risk free and safe working environment for sustained livelihood and wellbeing of workers. Health and safety is a right of all workers and must in all instances be provided and protected to safeguard human lives from work- related accidents and illness.

Occupational Safety and Health (OSH) as described is a situation that affects, or could affect the health and safety of employees, thus; permanent, temporary, and or contract workers, visitors, or any other person in the workplace. The construction industry world over is often appreciated as a catalyst to the growth of developing economies (Anaman and Osei-Amponsah, 2007). Indeed, the construction industry plays a very significant role in economic development; thus through the creation of jobs and infrastructure in most developing countries (Fugar and Agyakwa-Baah, 2010; Amoah, Ahadzie, and Ayirebi, 2011). The construction industry in low-income countries is characterized by the employment of large numbers of casual workers (Africa Development Report 2007), which makes the employment of casual workers the highest compared to other sectors of the economy. Similar to other developing and low-income countries the construction industry has a higher accident rate than many other economic sectors (Arslan, and Kivrak, 2009). Kheni, (2008) espoused that casual workers were exposed to dangerous chemicals, dust, high noise levels, as well as exposure to vibration within their working environment. Casual workers in developing countries, therefore face dangerous site risks, yet supplementary measures employed to control this situation are unsatisfactory (Kheni, 2008).

The International Labor Organization (2001) strongly emphasized that construction has the ability to absorb the excluded which creates employment for those with little education or skill, many of them from the poor sections of society. The ILO, 2001 further states that in low-income countries, which are characterized by high unemployment rates and low wages, human labour should be preferred and engaged. The employment of more casual workers has consequently resulted in high rate injuries and accidents which can, however, be attributed to unsafe attitude and behaviour occasioned by the non-compliance of occupational safety and health regulations. The study sought to find out the perspective of casual workers compliance to occupational safety and health (OSH) practice in the Ghanaian construction industry as well as strategies to improve the compliance level of casual workers. The nature and behaviour factors portrayed by construction casual workers in reneging safety practices are also discussed.

The majority of occupational health and safety concerns in the construction industry are injuries as a result of fall of objects from a height causing injury to the head, struck by, caught in/between incidence and electrocution (Okoye, P. U. and Aderigbe, Y. W, 2014), stepping on of a sharp object with barefoot or un-prescribed boot, falls of the employee from a height (which was determined as the highest occurrence of injury at construction sites (Okae-Adow, 2013), and the use of un-prescribed tools for the work. Personal Protective Equipment's (PPEs) are designed to be used to

eliminate or reduce the occurrence of these injuries, United Kingdom Regulations of (1992) and they include; hard hat, overalls, safety footwear, gloves, eye protection and eye visibility vest. Laryea (2010) asserts that in considering control measures to fatalities and accidents at the construction site, employers must endeavour to have PPEs available, however emphasis must be made to ensure that wearing the personal protective equipment is a prerequisite to have access to the construction sites by workers and visitors.

Compliment to the challenges of enforcing health and safety regulations on construction sites by the labour and factory inspectorate departments, indiscriminate display of attitude and unsafe behaviour showed off by workers (poor safety culture) prevail at the construction sites (Oswald, D., Sherratt, F., and Smith, S., 2013). The alarming rate at which construction workers continue to exhibit unsafe attitudes and behaviour at construction sites, therefore, calls for a serious rethink.

LITERATURE REVIEW

Casual workers in Ghana

Section 74 (1) and (2) of the Ghana labour Act, 2003, Act 651 characterises casual workers as temporal employees whose contract of employment need not be in writing. Their employment is limited to a maximum period of six (6) months and they are entitled to same remuneration for same quantum of work done in the establishment and to also enjoy health care services as enjoyed by all employees. In accordance with section 35, casual workers are entitled to be receive compensation for overtime engagement and also to receive full minimum wage for each day on which he attends work, regardless of whether or not the weather prevented him from carrying on his or her normal work and whether it is possible or not, to arrange alternative work for the worker on such a day.

Contrary to the generic characteristics of a casual worker as outlined above, several studies have shown contrary work situations. Casual workers work in an illegal environment; thus, they have been engaged by firms for more than six (6) months. Furthermore, the lack of construction legislations that protects the interest of the casual worker has resulted in their exploitation, leaving them with no other alternative than to settle for the poor working conditions or risk being laid off (Kheni, 2008). Laryea (2010) reiterates the deprivation of casual workers of their safety rights, even when they demand them in unsafe working conditions. This situation can be attributed to the weak health and safety legislations and lack of sanctions for health and safety violations in the Ghanaian construction industry as well as the unsafe behavioural attitude of casual workers.

Enforcing OSH in Ghana

The two major government institutions responsible for health, safety and welfare administration in Ghana are the Factory Inspectorate Department (FID) and Labour Department (LD). These departments are under the Ministry of Employment and Labour Relation. Enforcement of workplace health and safety standards is undertaken by the Factory Inspectorate Department. As prescribed by the Factories, Offices and Shops Act, 1970 (Act 328), the Factory Inspectorate Department and the Labour Department ensures that all workplaces maintain minimum standards of health and safety (Kheni, N. A., Gibb, A. G. F. and Dainty, A. D. F., 2006). Further to undertaking workplace inspections, the department conducts workplace surveys, provides occupational safety and health information, registers factories including construction sites and proactively promotes workplace health and safety

through workshops and seminars. The Labour Department, on the other hand, is accountable for administering the Labour Act, 2003 and the Workmen's' Compensation Act, 1987. Kheni, 2010 argues that human and logistical constraints, faced by the two departments have stifled their operational efficiency. In an environment where enforcing agencies such as the labour and the factories inspectorate department are stifled with logistics and staff to keep up their duties of ensuring sustainability of health and safety leaves nothing but an unsafe construction industry.

Factors Influencing Sustainable OHS practices in the Ghana Construction Industry.

The level of risk resulting in injuries and sometimes death on the construction sites is of great worry to industry players. The high numbers of injuries recorded of the period, however, contributes negatively to the performance and general outlook of the industry. Kheni (2006) cited Gibb and Bust (2006), and enumerated; improper use of equipment's, unregulated practices on construction sites and challenge in communication due to low literacy level as factors that negatively influence the sustainability of health and safety practice of construction industries in developing countries. This could be linked to ignorance of the law or mere refusal to comply with the law. The high level of illiteracy of workers in the construction industry requires close supervision and monitoring. Laryea (2010) reported that poor enforcement of health and safety policies and procedures posed a challenge in contributing to the unsafe health and safety problems in the Ghanaian construction industry. The attitude of construction workers was ranked third as a contributing factor for the poor compliance to health and safety requirement in Ghana (Dadzie, 2013). Absence of awareness about site safety and the aversion to wearing Personal Protective Equipment (PPE) were identified as main causes of poor safety practices in construction sites (Vitharana, V. H. P., Subashi De Silva G. H. M. J. and Sudhira De Silva, 2015; Aksorn, T. & Hadikusumo, B.H.W., 2007). A major challenge in the administration of occupational safety and health in Ghana has however been linked to the lack of a comprehensive national OSH policy by Puplampu, and Quartey, (2012) as well as the inability of the country in ratification of the International Labour Organisation (ILO) Convention, 1981 (No. 155) (Zakari, 2016).

RESEARCH METHODOLOGY

The aim of the study was to find out the perspective of casual workers on the compliance to occupational health and safety (OHS) practice in the Ghanaian construction industry as well as to identify sustainable OSH strategies to improve the compliance level of casual workers. In achieving this aim, the study brought together forty-eight (48) casual workers from eleven (11) construction firms across the Ghanaian construction industry. A structured interview questionnaire survey was used to elicit data from casual workers. Respondents were randomly selected after a formal permission had been secured from the project managers since the interview process stalled the output of the casual worker being interviewed. There were no special criteria for construction firm and casual worker selection. The eleven (11) construction firms were a mix of small and medium scale construction firms as well as large construction firms; D1/K1, D2/K2, D3/K3 and D4/K4 (Classification of construction firms in Ghana) with D1/K1 & D2/K2 regarded as large firms and D3/K4 & D4/K4 as small medium construction firms. Data was analysed basically using descriptive statistics. Randomly, any construction firm that was identified with workers on site, as well as work going on, was visited.

Table 1. Profile of construction firms and respondents

Classifications of Construction firm		Frequencies Construction firms	Percentage respondents	Frequencies Casual workers	Percentage respondents
Big Firms	D1/K1	1	27%	2	23%
	D2/K2	2		9	
Small Firms	D3/K3	6	73%	17	77%
	D4/K4	2		20	
TOTAL		11	100%	48	100%

FINDINGS

The impact of occupational health and safety on the industry cannot be overemphasised. Sustainable health and safety practices offer a risk-free and safe working environment which influences productivity. It is, therefore, imperative for all construction firms to provide a safe and favourable working atmosphere for their workforces by **providing** and **ensuring** the **compliance of OSH** by all workers, particularly casual workers. Out of the eleven construction firms visited, firms with classification numbers D1/K1, D2/K2, D3/K3 and D4/K4 had frequencies of 1, 2, 6 and 2 respectively, representing an approximate twenty-seven percent (27%) and seventy-three percent (73%) of large firms and small & medium scale firms respectively. Casual workers interviewed also showed a ratio of eleven is to thirty-seven (11:37) for large firms and small & medium scale firms respectively. The study revealed an eighty-two percent (82%) poor compliance with basic OHS regulations by casual workers. Significantly, the study also revealed that sixty-two percent (62%) of employers (contractors) did not provide PPEs for casual workers, compelling them to work under unsafe working conditions. This was because employers felt they were not obliged to do so under the contract (**ignorance**), and sadly, consultants were **reluctant to enforce** health and safety provisions of the contract. The mix of both behaviours of ignorance and reluctance to enforce provisions of the contract exacerbated the compliance level of casual workers to OHS. In a sharp contrast, however, personal protective equipment's were provided for full-time workers of most of the construction sites visited. Interestingly, some casual workers having regard for their personal health and safety, in some occasions provided PPEs for themselves. Whilst a majority of them, about ninety percent (90%) could not afford them, few numbers of casual workers were just not ready to own PPEs (even if they could) because they did not intend to stay on the work for a long time.

CONCLUSIONS/RECOMMENDATIONS

The sustainability and improvement of the construction industry is significantly dependent on OHS (Charles Chiocha, John Smallwood and Fidelis Emuze, 2011) and as such a matter for all stakeholders to uphold. Sustainable OSH management practices, therefore, must be enhanced. Occupational safety and health equipment should be made available for the use by all workers and visitors to curb the many injuries at construction sites. Recommendations are made for the empowerment of the factories inspectorate and labour departments to effectively undertake their mandate under the law, the merger of all occupational safety and health policy documents into one single comprehensive national OSH policy document is recommended and finally the passage of the construction industry bill (CIB) to ensure strict compliance by industry players in the implementation of projects and sustainable health and safety related matters. In conclusion, strict compliance to OSH practice of

casual workers should be ensured through first of all the provision and education on the use and importance of PPE's and secondly the provision of close supervision for compliance at site; thus wearing a PPE must be a pre-requisite to access to site, safety education for workers should be undertaken as well as ensuring that occupational safety and health compliance declaration be considered a basic contractual requirement for the award of projects (at least for government of Ghana funded projects), and punishable for non-compliance.

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PRIMARY HEALTH PROMOTION (PHP) IN THE SOUTH AFRICAN CONSTRUCTION SECTOR

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Keywords: Construction, Primary health, Performance.

ABSTRACT

The maintenance of the health of workers in industrial communities presents special problems and priorities, which are exacerbated in developing countries such as South Africa, by socio-economic realities. Lifestyle, communicable diseases, alcohol and drug abuse are issues, which extend far beyond the boundaries of society, impacting on individuals' performance in the work place. Health issues affect the ability to work, as work affects underlying health issues. The objectives of the study were to determine general contractors' (GCs') perceptions and practices relative to primary health promotion in construction.

A self-administered mostly closed-ended questionnaire was delivered per e-mail to primarily the award winners of regional and national health and safety (H&S) competitions. Frequencies and a measure of central tendency in the form of a mean score (MS) were computed to discuss the findings.

The findings indicate that limited PHP is undertaken in South African construction. However, GCs perceive that PHP does and would benefit employees and employers, the benefits including improved health and project performance manifested in, inter alia, lower absenteeism, and improved productivity, and quality. The majority of respondents' organisations provide primary health medicals annually and then on a free basis.

Conclusions include: PHP is not as important as the eight other parameters referred to in the study; PHP has an important role to play, particularly with respect to the 'high profile' PHP issues, namely alcohol abuse, HIV & AIDS, drug abuse, high blood pressure (hypertension), TB, and STIs, and the respondents are likely to constitute the more committed GCs.
Recommendations include: research should investigate the health status of construction workers, and the benefits thereof; GCs and industry associations should be made aware of the benefits of PHP, and industry H&S programmes should be amended to address the various facets of PH due to the relationships with OH.

INTRODUCTION

The World Health Organization (WHO) describes occupational health as being required to aim at the promotion and maintenance of the highest degree of physical, mental and social well-being of workers. Workers should be protected from risks resulting from factors adverse to their health and adapting the workplace to their physiological and psychological capabilities (Adisesh, 2012; Kortum, 2014b). The Bangkok Charter cites health promotion as a process of enabling people to increase control over their health and its determinants, and thereby improving their health. PHP could therefore be deemed an enabler, allowing people to be active participants in their own health status, ultimately placing a curb on ill-health, and increasing the quality of life. A healthy workforce is imperative for economic growth and global competitiveness. Workplace PHP should be a continuous process and continuously improved (Seoke, 2013). Community based PH care is one of the methods of health care delivery, where PHP occur. However, access to health facilities and inequities in the delivery of health care services, there remains a lack of access to both health care and PHP (Tanser, Gijsbertsen and Herbst, 2006). The South African Constitution dictates the requirement of the rights of workers irrespective of their health status, as well as the need to ensure their health is therefore maintained (Republic of South Africa (RSA), 1996).

LITERATURE REVIEW

The construction sector

It is widely accepted that construction project performance is generally based on the triangular model of cost, quality, and time rather than including H&S (HSE, 2004; Hinze, 2006; Smallwood, 2009; Windapo and Oladapo, 2012; cidb, 2015). Construction work is tough, dirty, and hazardous and involves high levels of manual and / or physical activity.

The effect of health on work

Working life does not begin or end at the entrance to the work, and a range of exposures occur prior to, and post the working day. A worker is exposed enroute to work, in traffic, at home and in the community, to food, other people, parasites, stress and general psychosocial issues prevalent in the area (Snashall and Patel, 2012). Therefore, it is not a straightforward matter to determine whether a health problem is as a result from exposure at work, from a particular hazard, such as erecting or dismantling scaffold components. Conditions such as chronic back pain in a construction worker from excessive physical activities can be difficult to attribute to occupational exposure when activities external to work could contribute to symptoms. The scaffold erector could have sports or hobbies which place musculo-skeletal load, and therefore if symptomatic would not be able to definitively determine if the cause of the chronic pain is from their hobby, or work. Furthermore, workers cannot be seen as isolated individuals, but as members of families. Problems at home are likely to affect performance at work, and increase the possibility to injury (Snashall, 2012; Pretorius, 2013).

An effective, comprehensive holistic and multi-sectoral approach is optimum to deliver PHP interventions. PH in the workplace is as essential as the health of workers, and is not only determined by hazards exposed to at work, but social and individual factors too. Workers that are healthy and safe at work are able to produce more than those who are ailing. The state of health is not only a result of individual behaviour, but aspects outside of the individuals' control (Williams, 2012; Malecela and Mayige, 2013; Ngowi, 2013; Seoke, 2013).

Adverse working and employment conditions result in limited possibilities for a balanced lifestyle, and result in chronic non-communicable diseases (NCDs), which are largely preventable, according to the WHO. NCDs such as depression and other mental health disorders, cardiovascular diseases and other diseases such as cancer, chronic obstructive and other pulmonary diseases. Such conditions can be successfully managed and addressed through the workplace. The WHO estimates that NCDs cause more than 36 million deaths per annum. Cardiovascular diseases account for more than 17 million deaths, 7.6 million deaths from cancers, and 1.3 million from diabetes. Individual risk factors such as unhealthy diet, excessive alcohol consumption, smoking and sedentary lives, high blood pressure, obesity, high sugar and cholesterol levels. Good welfare facilities not only improve workers' welfare on a personal level, but enhance efficiency at work (Malecela and Mayige, 2013; Kortum, 2014a; Muiruri and Mulinge, 2014).

Travel

The world currently embraces a global enonomy, where travel has become a common feature of work, and employees are often required to be 'transnationally competent'. Those who travel are exposed to a variety of hazards that may not be present in their home country. It has been identified that up to 30% end up being unwell, being confined to bed. Expatriates are noted to have higher illness rates, including injury, violence and psychological problems. Sexually transmitted infections (STIs) are a major consideration for travellers with up to 50% of short-term travellers having reported having had sexual relations with new partners, and up to two-thirds reporting variable condom use (Smith, Leggat and Patel, 2012).

Aging workers

The number of older workers is rapidly increasing, and is now a global issue, and includes Africa. Age management is implemented in Europe and other developing countries, but not in Africa. Age affects physical, functional, and intellectual capabilities, and deemed a non-modifiable factor, influencing the lives of those who live longer. Aspects such as providing alternative tasks or redesigning the workplace are aspects that need to be considered for the older worker (Cisse, 2015). Encouraging longer working lives reduces pension longevity, retains the experience and skills of older workers. Overall, those with higher levels of education, skills and training have been shown to maintain high levels of productivity where given a supportive and conducive working environment. Functional capacity appears to reduce post 30 years of age. The reduction in health level appear to affect the cardiovascular, respiratory, metabolic, and muscular functions. A reduction of 20% in physical work capacity is prevalent between the ages of 40 and 60 years, due to the decrease in aerobic and musculoskeletal capacity. Hearing and vision are also affected. Screening measures need to consider the effect of ageing, and the appropriate management of workers (Harper, 2012).

Absenteeism and presenteeism

Absence from work affects businesses and communities. In a large number of industrialised countries, approximately 35-45% of absenteeism from work is attributed to mental health issues or stress. Psychiatric disorders are more frequently being noted, and could result in 'presenteeism', which is where the individual is not well enough to work, but remains at work so as not to appear sick or perhaps lose their job due to lack of performance. Stigma's attached to the aspect of mental health include delayed treatment and return to wellness (Harvey and Henderson, 2012).

Stress

Psychosocial hazards have become a global phenomenon, but remain largely ignored. The WHO estimated approximately 400 million worldwide suffer from mental or neurological disorders, or other problems that are related to smoking, alcohol usage, and drug abuse. A number of other health outcomes noted as work-related stress are further noted and include cardiovascular disease, musculoskeletal disorders, and depression. Up to 40% of labour turnover is deemed to be from stress.
In developing countries, workers do not have access to health care and continue working to generate income, despite their being ill or disabled. The impact on the workplace results in reduced productivity and a high level of personal suffering. The management of stress could be through primary prevention through ergonomic interventions, organisational design, and management development. Secondary prevention through worker education and training, and tertiary prevention through sensitive and responsive management (Kortum, 2014b; Mukhalipi, 2014).

Occupational Health and Primary Health Promotion

Occupational health is the study of the effect of work on an individual, both good and bad, and conversely, the effect of the individual's health on her / his work. Most often referred to as fitness for work. The health of workers is determined by not only social and individual factors, and access to health services. Those workers who are from the poorer sectors do not have access to good health care, and are likely to have higher mortality and morbidity rates. The lack of symptom identification leads to neglect, and the development of NCDs. Health is not only a product of individual behaviour, but also forces outside of the individual's control. Aspects such as violence, crime levels, and redundancy further affect the individual (Snashall and Patel, 2012; Ngowi, 2013; Pretorius, 2013).

In South Africa, non-occupational diseases and illnesses have a great influence on the well-being and working capacity of the industry. Such conditions can further limit the ability to employ such workers seeking work, due to the risk factors of the industry. Diseases such as epilepsy restrict a worker from being near moving machinery, driving or working near water or heights. Colour blindness affects those who need to be able to distinguish colours at work, and diabetes where not controlled, poor vision, circulation and healing. Other conditions such as HIV and AIDS, malaria and influenza are further aspects that affect the worker and her / his ability to work safely and without risk to both employee and employer (Pretorius, 2013).

The construction industry undertakes minimal OH interventions, other than where there is a statutory requirement. Workers have minimal access to OH, with a very small number of employers providing any form of OH care in the form of ongoing medical surveillance or primary health care. Reasons given by the construction sector for the lack of attention to OH include the lack of available resources in terms of the costs allowed for the project, and prior to the revision of the Construction Regulations in 2014, there being no statutory requirement to do so (Deacon, 2004; Deacon, 2016).

The lack of medical surveillance and attention to underlying conditions leads to particular risk to the project. The potential risk of injury to the worker is raised, and could include fellow workers, where workers are placed with existing health issues. For example, the uncontrolled diabetic who has a peripheral neuritis (damage to the nerves supplying the limbs) that could affect the worker's feet. Where such damage exists, and the worker is required to climb, or is building access scaffolding, is

not able to feel adaquately and could be fatally injured in a fall. A worker with poorly managed hypertension (high blood pressure) could have a myocardial infarction (heart attack) while operating heavy equipment, and could fall, causing the workers and / or the death of other workers below, as well as the loss of equipment, time, and productivity (Deacon, 2004).

Primary Health Care delivery

NCDs are becoming more prevalent globally, but especially in Sub-Saharan Africa. Lower and middle income countries account for 80% of deaths from NCDs. In Tanzania, health promotion is noted as challenging due to part-time employment and the bet of informal workplaces (Ngowi, 2013). Malecela and Mayige (2013) state that in order for PHP to be meaningful and to increase the wellbeing of workers, PHP should focus on individual behaviour, work organisation and design. Programmes in place cover a range of national health issues, but are not linked to construction. The focus on communicable diseases such as HIV and AIDS, Tuberculosis (TB), diarrhea and upper respiratory infections have attracted attention over the past few years. NCDs are cited as creating a double burden to individuals and the health system in general, and that the loss of income will relate to approximately 0.5 billion dollars to cardiovascular diseases and diabetes. The workplace involvement is noted to include a multi-sectoral approach, using existing workplace screening programmes that include workplace health promotion (Malecela and Mayige, 2013; Ngowi, 2013).

Health promotion is noted as an active processs in the South African occupational setting. Programmes actively directing changing attitudes and influencing behaviour. Provision of PH programmes assist to make health a priority in the individual's value system, and ensure that information is provided on HIV and AIDS, fitness, and lifestyle related issues (Pretorius, 2013).

RESEARCH

Research method

A questionnaire consisting of primarily closed end five point Likert scale type questions – 4 / 6 non-demographic questions were closed end. The questionnaire, was circulated per e-mail to primarily H&S competition award winners at national and regional level, the rationale being to determine so called 'better practice H&S' GCs' perceptions and practices relative to PHP. Furthermore, only the management of GCs were surveyed, as they make decisions and allocate resources, and therefore in terms of the future of PHP in construction, a positive disposition on their part with respect to PHP is required to realise a 'paradigm shift' in the construction industry. A total of 16 responses were included in the analysis of the data. Given the limited size of the sample strata and the number of responses the study can best be described as exploratory, and furthermore, not representative, given that the respondents were 'better practice H&S' GCs.

Descriptive statistics in the form of frequencies and a measure of central tendency in the form of a mean score (MS) were computed in order to present the findings of the empirical study. The MS is based upon a weighting of the responses to the five point Likert scale type questions, and ranges from a minimum score of 1.00 to a maximum of 5.00, the midpoint of the range being 3.00. The MS thus enables the range of percentage responses to be interpreted, and also the parameters, the frequency at which PHP aspects are addressed, and the benefits of addressing the PHP aspects, to be ranked. Due to the number of responses, inferential statistical analysis was not possible.

Respondents were 43.4 years of age on average, and 18.8% were female and 81.2% were male. Respondents had worked on average 10.5 years for their current employer, and 16.5 years in construction. Qualifications ranged from certificates to diplomas to honours degrees, and disciplines ranged from architecture to construction management to environmental health. Occupations ranged from managing directors, site managers, to H&S Officers.

Research results

Table 1 indicates the importance of parameters to respondents' organisations in terms of percentage responses to a scale of 1 (not) to 5 (very), and a MS between 1.00 and 5.00.

It is notable that with the exception of the subject of the study – PHP, all the parameters' MSs are > 4.20 ≤ 5.00 – between more than important to very important / very important. However, the MS (4.19) of PHP is virtually on the lower point of the range. Cost, one of the three traditional project parameters, namely cost, quality, and time, is ranked first. Furthermore, it is notable that occupational safety (MS = 4.88) is ranked third, occupational health (MS = 4.69) is ranked sixth, and health and wellbeing (MS = 4.63) is ranked seventh as the latter two are related to PHP.

Table 1, Importance of parameters to respondents' organisations.

Parameter	Response (%)						MS	Rank
	U	Not …… Very						
		1	2	3	4	5		
Cost	0.0	0.0	0.0	0.0	0.0	100.0	5.00	1
Productivity	0.0	0.0	0.0	0.0	6.3	93.8	4.94	2
Occupational safety	0.0	0.0	0.0	0.0	12.5	87.5	4.88	3
Quality	0.0	0.0	0.0	0.0	12.5	87.5	4.88	4
Time	0.0	0.0	0.0	6.3	0.0	93.8	4.88	5
Occupational health	0.0	0.0	0.0	12.5	6.3	81.3	4.69	6
Health and wellbeing	0.0	0.0	0.0	18.8	0.0	81.3	4.63	7
Environment	0.0	0.0	6.3	6.3	18.8	68.8	4.50	8
Primary health promotion	0.0	0.0	6.3	18.8	25.0	50.0	4.19	9

Table 2 indicates the extent which workers benefit or would benefit from PH issues being addressed in the work place in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS between 1.00 and 5.00. It is notable that only one issue, namely alcohol abuse, has a MS > 4.20 ≤ 5.00 – between a near major to major / major extent. Alcohol abuse is a routinely experienced issue, including on construction sites in South Africa. Thirteen MSs are > 3.40 ≤ 4.20 – between some extent to a near major / near major extent. HIV & AIDS, drug abuse, high blood pressure (hypertension), tuberculosis (TB), and sexually transmitted infections (STIs), ranked to sixth are topical issues among workers in South Africa in general. Two MSs are > 2.60 ≤ 3.40 – between a near minor extent to some extent / some extent.

Table 2, Extent to which workers benefit or would benefit from primary health issues being addressed in the work place.

Issue	Response (%)						MS	Rank
	U	Minor……..Major						
		1	2	3	4	5		
Alcohol abuse	0.0	6.3	0.0	12.5	18.8	62.5	4.31	1
HIV & AIDS	0.0	6.3	0.0	25.0	12.5	56.3	4.13	2
Drug abuse	0.0	0.0	6.3	31.3	18.8	43.8	4.00	3
High blood pressure (hypertension)	0.0	0.0	12.5	18.8	25.0	43.8	4.00	4
Tuberculosis (TB)	0.0	0.0	12.5	18.8	25.0	43.8	4.00	5
Sexually Transmitted Infections (STIs)	0.0	6.3	6.3	25.0	12.5	50.0	3.94	6
Healthy eating (nutrition)	0.0	6.3	6.3	25.0	25.0	37.5	3.81	7
Stress	0.0	6.3	6.3	37.5	6.3	43.8	3.75	8
Smoking	0.0	0.0	18.8	31.3	12.5	37.5	3.69	9
Cancer	0.0	6.3	6.3	43.8	6.3	37.5	3.63	10
Family violence	0.0	6.3	6.3	43.8	6.3	37.5	3.63	11
Worms, family illnesses e.g. Measles)	0.0	0.0	12.5	43.8	18.8	25.0	3.56	12
Family planning	0.0	6.3	6.3	50.0	6.3	31.3	3.50	13
Sugar diabetes (diabetes)	0.0	6.3	6.3	50.0	6.3	31.3	3.50	14
Controlling weight (obesity)	0.0	6.3	12.5	50.0	6.3	25.0	3.31	15
Epilepsy	0.0	6.3	25.0	37.5	0.0	31.3	3.25	16

Table 3 indicates the frequency at which respondents' organisations address PH issues with workers in terms of percentage responses to a scale of annually to weekly, and a MS between 1.00 and 5.00. It is notable that no PHP issues have MSs > 4.20 ≤ 5.00 – between fortnightly to weekly / weekly, and > 3.40 ≤ 4.20 – between monthly to fortnightly / fortnightly. The top two ranked issues have MSs > 2.60 ≤ 3.40 – between quarterly to monthly / monthly, namely alcohol abuse, and drug abuse. These two issues are topical in the South African construction industry in that such abuse occurs on sites. The issues ranked third to ninth have MSs > 1.80 ≤ 2.60 – between annually to quarterly / quarterly. Smoking, HIV & AIDS, high blood pressure (hypertension), STIs, and TB are common issues in the South African construction industry. The remaining issues ranked tenth to sixteenth have MSs > 1.00 ≤ 1.80 – between annually to quarterly.

Table 3, Frequency at which respondents' organisations address primary health issues with workers.

Issue	Response (%)						MS	Rank
	Unsure	Annually	Quarterly	Monthly	Fortnightly	Weekly		
Alcohol abuse	0.0	12.5	18.8	31.3	6.3	31.3	3.25	1
Drug abuse	0.0	25.0	18.8	31.3	0.0	25.0	2.81	2
Smoking	12.5	37.5	12.5	12.5	6.3	18.8	2.50	3
HIV & AIDS	0.0	37.5	25.0	31.3	6.3	0.0	2.06	4
High blood pressure (hypertension)	12.5	31.3	31.3	18.8	6.3	0.0	2.00	5
Sexually Transmitted Infections (STIs)	6.3	37.5	25.0	31.3	0.0	0.0	1.93	6
Tuberculosis (TB)	18.8	37.5	12.5	31.3	0.0	0.0	1.92	7
Healthy eating (nutrition)	20.0	40.0	13.3	26.7	0.0	0.0	1.83	8
Family planning	25.0	43.8	12.5	12.5	0.0	6.3	1.83	9
Family violence	25.0	37.5	25.0	12.5	0.0	0.0	1.67	10
Stress	25.0	43.8	12.5	18.8	0.0	0.0	1.67	11
Sugar diabetes (diabetes)	25.0	37.5	31.3	6.3	0.0	0.0	1.58	12
Controlling weight (obesity)	25.0	43.8	25.0	6.3	0.0	0.0	1.50	13
Cancer	18.8	50.0	25.0	6.3	0.0	0.0	1.46	14
Worms, family illnesses e.g. Measles	31.3	50.0	6.3	12.5	0.0	0.0	1.45	15
Epilepsy	37.5	50.0	12.5	0.0	0.0	0.0	1.20	16

Table 4 indicates the extent to which respondents' organisations would benefit relative to aspects as a result of PH aspects being addressed in the work place in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS between 1.00 and 5.00. It is notable that 6 / 8 (75%) of the issues have MSs > 4.20 ≤ 5.00 – between a near major to major / major extent. It is notable that the top three aspects are project performance related - Improved productivity, enhanced schedule / time performance, and enhanced quality. Reduced absenteeism ranked fourth, which affects project performance, is also a function of enhanced general health, and reduced stress levels at work, ranked sixth and seventh. Prevention of disease, and prevention of injuries, ranked seventh and eight respectively, have MSs > 3.40 ≤ 4.20 – between some extent to a near major / near major extent.

Table 4, Extent to which respondents' organisations would benefit relative to aspects as a result of primary health aspects being addressed in the work place.

Aspect	Response (%)						MS	Rank
	U	Minor……Major						
		1	2	3	4	5		
Improved productivity	0.0	0.0	0.0	6.3	25.0	68.8	4.63	1
Enhanced schedule / time performance	0.0	0.0	0.0	6.3	31.3	62.5	4.56	2
Enhanced quality	0.0	0.0	0.0	6.3	37.5	56.3	4.50	3
Reduced absenteeism	0.0	6.3	0.0	6.3	18.8	68.8	4.44	4
Enhanced general health	0.0	6.3	0.0	6.3	25.0	62.5	4.38	5
Reduced stress levels at work	0.0	6.3	0.0	12.5	25.0	56.3	4.25	6
Prevention of disease	0.0	6.3	0.0	12.5	31.3	50.0	4.19	7
Prevention of injuries	0.0	6.3	6.3	6.3	25.0	56.3	4.19	8

Table 5 indicates the extent to which respondents' organisations conduct medical screening that also addresses primary health aspects, and primary health medicals for staff. In terms of medical screening, the majority of respondents' organisations do so relative to all categories. This is to be expected as many PH and occupational health issues are interrelated. With the exception of the management category, the majority of respondents' organisations conduct primary health medicals for staff, and then at no cost (free) for the recipients.

Table 5, Extent to which respondents' organisations conduct medical screening that also addresses primary health aspects, and primary health medicals for staff.

Category	Response (%)							
	Medical screening		Primary Health Medicals				Cost	
	No	Yes	No	Half-yearly	Annually	2-Yearly	Free	Cost
Management	18.8	71.2	37.5	0.0	56.3	6.3	88.9	11.1
Supervisors	6.3	93.7	20.0	6.7	66.7	6.7	91.7	8.3
Workers:								
• Skilled	6.3	93.7	20.0	6.7	66.7	6.7	100.0	0.0
• Semi-skilled	6.3	93.7	20.0	6.7	66.7	6.7	100.0	0.0
• General	6.7	93.3	21.4	7.1	64.3	7.1	100.0	0.0

DISCUSSION

The literature indicates the existence of underlying medical conditions which have been identified as critical to the ability of a worker to perform their duties with minimal effect on their work, and to work at optimal levels. Similarly, the ability to address and assist with the management of such underlying conditions such that both workers and employers benefit, including society at large. The increased requirements of workers to travel away from home to work, and the high level of illnesses, levels of STIs that affect the greater community, as well as the worker's family are a cause for concern. Aging workers are physically not able to work at the same rate or physical level as their younger colleagues, and stress adds to the burden. Psychological disorders are increasing and often workers are present at work, despite not being well. Access to health care from work or the community is challenging, and often the relationship between PH and OH issues are not therefore identified or appropriately managed.

The empirical findings generally reflect the findings of earlier research conducted by the researchers (Deacon and Smallwood, 2003), particularly in terms of the frequency that PH issues are addressed, the extent to which employees would benefit from employers addressing various PH related aspects, and the benefits arising from employers addressing various PH related aspects with their employees.

CONCLUSIONS

PHP is not as important as the eight other parameters referred to in the study. The traditional project parameters, namely cost, quality, and time are more important despite the respondents' commitment to H&S confirmed by their having achieved awards in regional and or national H&S competitions or contracting with the aforementioned. However, the high MSs relative to the parameters occupational safety, occupational health, and health and wellbeing further confirm their

commitment to H&S, which indicates that they are likely to be the more committed contractors in terms of H&S and also in terms of PHP, and therefore the findings are not necessarily representative of the general status in the industry.

Based upon the extent to which workers benefit or would benefit from PH issues being addressed in the work place, it can be concluded that PHP has an important role to play, particularly with respect to the 'high profile' PHP issues, namely alcohol abuse, HIV & AIDS, drug abuse, high blood pressure (hypertension), TB, and STIs. However, the frequency at which respondents' organisations address PH issues with workers does not correlate with the perceived extent to which workers benefit or would benefit from PH issues being addressed in the work place. However, given that the top three issues are alcohol abuse, drug abuse, and smoking, it can be concluded that they are thus due to their occupational safety implications i.e. alcohol and drug abuse being often linked with accidents, and smoking with fires. This is reinforced by the finding that medical screening addresses PH issues. The finding that the majority of respondents' organisations conduct primary health medicals for staff, and then at no cost (free) for the recipients, reinforces the conclusion that the respondents are likely to constitute the more committed GCs in terms of PHP.

The irony of the findings is the extent to which respondents' organisations would benefit relative to a range of performance aspects as a result of PH aspects being addressed in the work place, yet they do not address PH issues frequently. This is possibly attributable to barriers such as non-availability of training material, a lack of PHP expertise, and other resources. Furthermore, PHP is not a legal requirement.

RECOMMENDATIONS

All H&S related research should investigate the issue of PHP, and future PHP research should address the issue of 'barriers to PHP', and investigate the health status of construction workers. PHP, as an ongoing service within the construction sector, would add enormous value to managing the underlying health issues that face workers and their families daily. Furthermore, addressing such health issues could reduce the health risk level of projects in the construction sector, and increase the wellbeing and sustainability of the sector's human resources.

GCs, other contractors, industry associations, clients, project managers, designers, and quantity surveyors should be made aware of the benefits of PHP, and industry H&S programmes and competitions should be amended to address the various facets of PH due to the relationship with safety and OH.

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THE BENEFITS THAT TREES CAN BRING TO URBAN FUTURES

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ABSTRACT

Change is an inherent aspect of human civilization, and it is rarely comfortable. Cities across the globe are subject to constant change, and no urban area is likely to be immune from the forces that bring this about. Indeed, as the 21st century progresses, these changes are going to have to be far more radical than they currently are, if we want our future towns and cities to be resilient, be places that attract and retain innovative investment and development, and for them to contain happy, healthy and creative people. In the UK, we will have more than 8 million extra people by 2035, an increase of over 15% over the current population level. However we accommodate this expansion, the importance of incorporating a viable urban green infrastructure into our urban futures, articulated and defined by a designed urban forest, is being increasingly appreciated.

This paper will consider the significant and provable environmental, social, economic, financial and cultural benefits that urban forestry can bring to the urban realm, specifically considering the use of the urban forest in improving public health and happiness and improving the air quality of our urban areas. This issue is of some concern to the current UK Government, as it has admitted that some 60,000 premature deaths occur annually in the UK as a result of diseases stimulated by poor urban air quality, over 360 of which occur in Leeds City Centre and environs.

The speed and scale of urbanization continues to increase. The European Environment Agency has suggested that 60% of the urban areas that will exist in the world in 2030 have yet to be built. Thus the proper planning, design, implementation and management of our urban forests will become increasingly important, as they will become one of the prime vehicles for delivering the necessary quality of human life in our resilient urban futures.

INTRODUCTION

Human beings have had a long, deep, cultural relationship with trees, woodlands and the landscape. This relationship transcends national cultures, and happily sits as an equal alongside our scientific, economic, ecological and our spiritual relationships. Indeed, as W H Auden reminded us, "A culture is no better than its woods" [Auden, 1973]. Thus trees have been a vital component of our cultural relationships with our landscapes since time began.

Although our relationship with the landscape, trees and woodland was initially more to do with survival, shelter and spirituality, it could be argued that the relationship quickly became an economic one, where trees and the landscape provided many of the essentials of life – food, building materials, household materials, fuel, chemicals and other raw materials. The felling and clearance of trees to make way for agriculture and the expansion of human civilisation is an activity that has gone on practically uninterrupted for thousands of years, and is still continuing in many parts of the world today. Thus because trees, or rather the wild forest, has always stood in the way of human progress, it might appear that mankind would have little regard for such natural objects.

Paradoxically, this is very far from the truth, and whilst man has seemingly striven in recent times to tame nature, in earlier times trees have had a peculiarly dominant influence upon both human life and the human imagination. Given the short and erratic human life span, trees must have seemed immortal, especially the evergreens, which remained throughout the year apparently unchanged and unaffected by the natural cycle of the seasons upon which survival depended. Trees, as well as supplying basic human needs, have deeply effected human spiritual development. If this appears to be a somewhat extravagant claim, this is only because, compared to our forebears, we are nowadays more alienated and divorced from the land, the natural world and natural processes (Frazer, 1922).

This happy relationship between people, trees and their landscapes began to get more refined, as scientific and economic cultures tended to gain the upper hand; an upper hand that resulted in revolution – the Agrarian Revolution and the Industrial Revolution. Once people began to congregate together to create towns and villages, the resultant demands upon the new townscapes refined still further. Trees were still a valuable aspect of such townscapes, but would have been selected more for their specific attributes, be they for food, fuel or shelter.

Ever since they were created towns, cities and their urban landscapes have been, and continue to be, subject to constant change, and no urban area is likely to be immune from the forces that bring this about. Indeed, as the 21st century progresses, the urban landscapes of our towns and cities are going to have to change far more quickly and radically than they are at present, if we want them to be resilient and provide and maintain a healthy setting for people, places, biodiversity and investment. It is known that the pace of urbanisation will accelerate as towns and cities respond to this change – changes in population, in the economy, in ethnic composition, climate change, and in people's expectations and demands of the places they inhabit. (Brotchie, et al, 1995).

In spite of being aware of these expectations and demands, it could be argued that the planning, design and management of the late 20th and early 21st century urban landscapes have all too often not created the liveable places of quality that their designers claimed they would do. Too much contemporary architecture and urban design has been criticised as being inhuman and repressive, despite the high social and political ideals shared by so many of the influential planners and designers of the time (see McGlynn 1993, for example)]. Urban design, landscape design and green infrastructures are at a cross roads however in many countries, as the concept of globalisation increases apace, post-industrialism takes hold and the quality of city centre urban life continues to decline as a result.

Thus, many cities continue to expand, often with standardised, low-quality developments, which encourages those citizens who have the available resources and opportunities to seek safer, greener, more pleasant, edge-of-town surroundings to inhabit, with an appreciably higher canopy cover of trees. The fact that the registration of private motor vehicles in Western Europe exceeds the registration of births by a factor of 4:1(EEA, 2006, p40.) suggests that, even with the high quality of most European public transport systems, people are opting for up-to-date personal transportation to support them in their new green suburban lifestyles, rather than having more children to support the population or themselves in their old age. The concept of urban sustainability is increasingly compromised as a result.

This paper will consider some of the issues posed by contemporary urban landscapes and urban design, and the essential role that trees can play in them. The pay-back and the benefits that we can still enjoy from trees and the urban forest being an integral part of where we live, work and recreate will be considered. The manner of the pay-back has differed over time of course, and maybe it is only relatively recently that we have begun to fully appreciate exactly what benefits flow from urban trees is in the 21st century, and how fundamental it is - and is going to be - to our urban futures.

The Developing Concept of Urban Forestry in the UK

The Agrarian and Industrial Revolutions imposed significant changes upon the landscapes of Europe, with the expansion of cities and the de-population of the countryside. The poor living conditions of the working classes, the new class conflicts that were arising and the pollution of the environment all contributed to a rising reaction against urbanism and industrialisation, brought about a new emphasis on the beauty and value of nature, trees and the landscape and began to establish the concept of "place". In their research on cultural identities across Europe, Jones and Cloke (2002) wrote of an appreciation of the growing importance and significance of the design of "place". Our attachment to "place" comes through an interplay of a whole range of meanings that are significant to us as individuals which, for most people, is likely to include a relationship to "wooded nature" and trees. It has been an appreciation of the design of place that has influenced the development of the concept of urban forestry.

It could be argued that the term "urban forestry" was something of an oxymoron, in that how can you locate a forest in a city? That said, it is generally agreed that the term "urban forestry" was coined by the late professor Eric Jorgensen of the Faculty of Forestry, University of Toronto in 1995 (Johnston, 1997, 2015). The term was subsequently adopted by urban arborists in the USA, where the Society of American Foresters set up an urban forestry working group in 1972, and the term allegedly arrived in the UK in the late 1970s (Johnston, 1997).

This view has been challenged by Simson (Simson 2002), who maintains that whilst the *term* urban forestry might well have been invented in the latter part of the 20th century, the concept of urban forestry as a *place-maker* and of using trees in a designed way as the mainstay of a wholesome urban environment goes back much further to the 19th century philanthropic Quaker industrialists, who actively deployed trees throughout their various industrial villages in their quest to improve the health, happiness and quality of life of their employees. Industrialist philanthropist Robert Owen, for example, the entrepreneur behind the development of New Lanark in Scotland stated that:

> "the presence of trees is pleasant to the eye, refreshes the workers and improves the health of the district". (Owen, 1816, p97.)

Such ideas, propounded by Owen and other inspired industrialists, began to promote other roles for trees, woodlands and urban green space at this time to counter the lack of the quality of life experienced by the majority of workers in the Industrial Revolution cities. Urban green was seen as providing potential "green

lungs" for the city and its inhabitants, and the fact that healthier workers meant healthier profits was not lost on these industrial entrepreneurs.

Different countries became urbanised at different times. For the UK, the date 1851 was significant, as that is when the country officially became an urban nation, as the census of that year proved, for the first time, that urban people outnumbered rural dwellers. One of the reactions to this rapid social, economic and physical change in the 19th century, and the resulting social unrest, was a concerted attempt to try to make things better by "greening the collective urban landscape". Trees were often at the epi-centre of these initiatives, and the first street trees were planted in London in 1823 along the well-to-do Margaretta Terrace in Chelsea. (Lawrence, 2006) Street tree planting had almost become 'the norm' in London by the end of the 19th century, although there were undertones of class distinction however. Dyos (1982), for example, commenting on the location and choice of tree species in the streets of Camberwell, London, observed that:

> "the choice of trees had its social overtones – planes and horse chestnuts for the wide avenues and the lofty mansions of the well-to-do; limes, laburnums and acacias for the middle incomes; unadorned macadam for the wage-earners".

Street trees, public parks and green space all started to become features of many towns and cities at this time. Indeed, all across Western Europe, wooded parks were becoming stages for the theatre of social order. Different social classes had their own way and their own time for using the wooded areas, thus reaffirming their place in the social pecking order. When the railway reached Fontainbleau for example, some 60 km from Paris, the woodland was turned into a "promenade parisienne", and mass recreation commenced (Kalaora, 1981). In the UK, the annual Dunlop Fair in Epping Forest attracted crowds of over 100,000 Londoners during the mid-1850s (Green, 1996).

As a result, attention turned to the accommodation of trees in the design of the urban landscapes that comprised the public realm in these expanding towns and cities. Such treed landscapes were primarily aesthetic however, and it was really only in the latter part of the19th century that the "collective landscape" emerged as a social necessity, because such landscapes were not just about aesthetics, but were a crucial part of ordinary people's everyday life.

By the end of the 19th century, the positive relationships between trees, people, their quality of life and the resulting social benefits were increasingly being appreciated by urban theorists, one of whom was Sir Ebenezer Howard, who published his book entitled *Tomorrow – a peaceful path to reform* in 1898 to promote these ideas. Howard had been much influenced by the ideas of George Cadbury, who was appalled by the terrible conditions of penury and squalor which surrounded his workers in industrial Birmingham. Cadbury embarked upon the design and building of a new housing estate in 1895 – Bournville – in the hope that he could prove to the political powers, legislators and his fellow industrialists that *good quality housing in a natural, green environment was not only a realisable aspiration, but a necessity for the greater good of society.* (Bournville Village Trust Archives).

He had some success with his quest as, in September 1901, over 300 men gathered in Birmingham for a conference to discuss "The City of the Future". This was the first urban planning conference to be held in the world (Hall, 1996). The conference was organised by Howard, who was in attendance, and the event was chaired by Cadbury. The choice of Birmingham for the conference was no accident, as Howard wanted the delegates to see and experience the success of Cadbury's work at Bournville.

Howard was not a designer however. He was an economist and a sociologist, but was very much influenced by the success of the design of Bournville and, as a result, he substantially revised his book *Tomorrow – a peaceful path to reform*, and re-published it in 1902 as *Garden Cities of Tomorrow*, which reiterated the value of incorporating trees and green space within designed urban development (Moss-Eccardt, 1973).

The resulting Garden City Movement in the UK, which stimulated the design and building of Letchworth and Welwyn Garden City and the setting up of the Town and Country Planning Association (Hardy, 1999), also influenced several model suburbs in the USA such as Radburn, Forest Hills and the Suburban Resettlement Programme. It also had some influence upon the "humane design principles" adopted by some developments in the Weimar Republic in Germany. Countless other new developments throughout the world, based upon a viable, green-space, treed structure have also been influenced by the Garden City Movement, and these were very much the driving force behind the post- war Labour Government's passing of the New Towns Act in 1946.

Street tree planting in the UK really became of age during the inter- and post-war periods, when large suburban estates began to be developed. Street names such as Acacia Avenue, Hawthorn Road, Cherry Tree Avenue and Lime Grove became synonymous with such developments. The amount of suburban development that was taking place in the UK at this time, and the gaining in popularity of including substantial numbers of trees within such developments, positively influenced UK Government thinking and set the ball rolling on a number of initiatives that could be deemed to be "urban forestry". These included the commissioning of a very successful Community Forestry Programme in 1989, the National Forest in the East Midlands, and the setting up of the National Urban Forestry Unit (NUFU) in 1995.

In spite of such initiatives, trees and the urban forest were still primarily seen as a "cosmetic" embellishment to hard development, rather than a fundamental aspect and articulator of place. The pace of urban change has been accelerating over recent decades however, and shows no sign of slowing down**.** The human reaction to this change and our increasingly hard urban perspective has tended to insulate and isolate us from our surroundings, including our trees. So many of us see the world as passive observers, safe in our homes, cars, offices or universities, through the lens of our smart phones, or through the intermediary of our TV or cinema screens. The late Hubert Humphrey hit the nail on the head when he said "We are in danger of making our cities places where business goes on but where real life, in the real sense, is lost".

That said, it cannot be denied that many people find a powerful attraction in "natural" green, treed landscapes, even in the city. They can give us deep aesthetic experiences of sublimity and beauty, or even perhaps that elusive return to a pre-Eden innocence which enables us to transcend, for a short moment in time at least, the pressures of our daily lives. Thus trees perhaps have a far greater role to play in our towns and cities than merely being seen as pleasant but essentially "cosmetic" additions to place.

The benefits of urban trees

Both urban design, urban landscapes and the "quality of place" of the urban public realm are at a crossroads, as the quality of urban life continues to decline, cities continue to expand as a result, and sustainability is at best static. A range of new ideas, concepts and sub-strands of urbanism are emerging as a result, concepts such as landscape urbanism, biophilic cities, biominicary and green urbanism to name but a few. All these concepts incorporate a central role for trees and urban forestry.

It has been argued by Simson (2008) that urban forestry was "rediscovered" at the end of the 20th century as a philosophical approach to having a strategic overview of the planning, design, establishment and prospective management of the whole mosaic of a city's urban and peri-urban green space, and all the implications that has to engaging with the associated social, economic and environmental issues and strategies that are to be found there. A growing canon of research has continued to emerge that proves that the inclusion of trees in and around the city has a broad spectrum of benefits – economic, financial, environmental and social (eg. The Green City www.thegreencity.co.uk, The Benefits of Urban Green Space www.vito.be/bugs , Trees for Cities www.treesforcities.org/html/informationrepo/ .)

More specifically, trees can greatly improve our health and well-being, improve learning, increase property values, provide focal points to improve social cohesion, improve air quality, offset carbon emissions, promote biodiversity, limit the risk of flooding, cool our towns and cities, promote inward investment and job creation and even make us drive more safely (eg. Konijnendijk, et al, 2005, Hiemstra,J, Schoenmaker-van der Bijl, E & Tonneijck, A, 2008). Such benefits, now known as Eco-System Services, can also have a financial value put upon them. Torbay Council for example were, in 2010, the first local Authority in the UK to value the benefits of their urban forest, which were estimated to be in excess of £280 million (Treeconomics 2011). London carried out a similar project in 2014, and the total annual benefits of their urban forest were estimated to be £132.7 million (Treeconomics London 2015).

One of the prime economic and social benefits of planting trees in urban areas is their ability to drastically reduce air pollution and thus improve the quality of human life (Beckett, K P, et al 2000). Poor air quality is a significant and increasing public health issue (eg. Nowak, Crane & Stevens 2006). As long ago as 2008, the burden of particulate air pollution in the UK, primarily from diesel-powered road traffic, was estimated to be responsible for 29,000 premature deaths from cancers and cardiovascular diseases (COMEAP 2010). Public Health England have estimated that some 350 workers and regular visitors suffer premature deaths annually in Leeds City Centre by air pollution caused by vehicular traffic (Gowers, Millar & Stedman, 2014).

It has been estimated that removing all the fine particulate air pollution – PM10's, PM2.5's, etc – would have a bigger impact on life expectancy in England and Wales than eliminating passive smoking or road traffic accidents. It is know that living adjacent to an urban main road has the equivalent effect on the health of human beings as being a passive smoker (Miller and Hurley, 2006). The UK Government has estimated that the economic cost from the impacts of air pollution in the UK is estimated at £9 - £19 billion per annum, which is comparable to the economic cost of obesity - over £10 billion. (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69340/pb13378-air-pollution.pdf)

All is not lost however. Vegetation captures both gases and particulates from the atmosphere more effectively than any other land surface (Smith 1981, Fowler, Cape & Unsworth 1989). Due to the leaves, stems and branches of their large canopy surface area and the air turbulence created by their structure, trees are much more effective in the uptake of these pollutants than shorter vegetation (Lovett 1994, Powe & Willis 2004). For example, Fowler et al (2004) found that trees and woodlands in the West Midlands attracted and collected three times more PM10 particulate pollution than grassland did.

Thus good quality plant life is increasingly being appreciated as being essential to improving the quality of the air in our urban areas, and therefore our health and quality of life. All plants can contribute to improving air quality, but trees, and even some specific species of tree, are more suitable than others at performing this role. Leaves are the key in filtering gases and attracting particulates, and the differences in the leaf structure of tree species and the quantity of their foliage play a crucial part in their ability to perform these roles. Much more research needs to be carried out into the effectiveness of specific species of tree in improving air quality however, particularly with the influence of climate change on the growth and performance of plants. Hiemstra, Schoenmaker-van der Bijl & Tonneijck (2008) have drawn together a useful league table of appropriate tree species based on available knowledge, but a revised and updated version carried out under COST Action FP 1204 GreenInUrbs is currently in press (www.greeninurbs.com).

Urban Forestry and Urban Futures

The provable benefits that trees can and do bring to the quality of the urban environment suggests that there is a need emerging for a responsive concept for planning, designing, constructing and managing sustainable, resilient towns and cities to emerge that is trans-disciplinary, cost effective, and easy to both understand and communicate to all levels of the community. If the conventional approaches to regulating the quality of our

post-industrial urban areas are no longer reliable, perhaps an opportunity exists for an alternative approach to develop? It might be an opportune time therefore for urban forestry to step forward and start getting involved in proposing cogently argued strategic, regional plans to seduce and convince the policy-makers and the public, just as urban planners had to do for city developments in the late 20th century. Urban foresters have the credentials to deal with these unstable conditions because urban forestry continually adapts and transforms itself and can accommodate a myriad of forces and initiatives. Urban forestry is getting more sophisticated and has moved beyond being seen as a 'green cosmetic' that all too often was used to legitimate poor planning, to becoming an integral part of new, more resilient Urban Futures.

What we have already learned is that cities are not only economic assets, not merely market places. They have a great capacity to promote community development, social cohesion and civic and cultural identity. The somewhat narrow pursuit of market-led success has not led to the elimination of social problems. Achieving economic success with social justice in sustainable, resilient cities remains a challenge to all governments and organisations – local, regional, national and international, and the concept of urban forestry can arguably assist in this quest.

If urban foresters are to deliver under this new Urban Futures agenda, we will from time to time have to leave the security of the trees and engage with concepts that are new and perhaps alien to us. For example, central to Urban Futures is the concept of "physical capital". This can be defined as "the potential value – financial, social and cultural – of the built environment", of which of course the urban forest is a vital part. Urban forestry is about creating and / or maintaining a good physical environment, and there is no doubt that it is socially, environmentally and economically desirable and valuable. But what is the nature of that value? How does the value accruing to the owners of property relate to the values of the wider public? Can any of these kinds of value be reliably measured? What is their relationship to other types of wealth, income or capital?

This is familiar territory for the economist; less so for the urban forester, particularly as such work can span a considerable number of years. Trees can last a long time; many other built environments on the other hand can come and go, or be re-furbished or re-built within a relatively short space of time. This can make life complicated, but if we genuinely believe that trees make great places and great places can make trees, and that urban foresters too make great places, and that such great places boost value for the public realm, we will have to learn the tricks of the Urban Futures trade, understand and subscribe to the subtleties of concepts such as physical capital, and participate in research to analyse and test these concepts so that we can construct a convincing case for urban forestry in our emerging polycentric cities.

At the heart of responsive urban forestry lies a belief in the quadripartite approach of research, experimentation, practice and reflection. This is a 'big idea', and it may be one of the 'big ideas' that will be part of the driving force behind the 21st century Urban Future perspectives in all our cities, whether they are in Europe or elsewhere. As Daniel Burnham, the visionary planner of Chicago said "make no little plans; they have no magic to stir men's bold…make big plans…aim high in hope and work". (Burnham, 1907).

In our responsive urban forestry mission to shape a better world, we must shape better cities, and the European Union is well aware that the future of Europe depends on having successful, sustainable, resilient cities and city regions (Potočnik, 2013). Helping to create such places, where people can aim high in hope and work is the potential role that urban forestry can take on in the emerging, world-wide Urban Futures, based very much on the premise that the true wealth of our towns and cities can only really be measured in terms of the health, well-being and the culture of our people, and the sustainability and resilience of their environment. Some would say that these responsive urban forestry promises are unrealistic, maverick views that cannot be realised in the contemporary urban debate. It could be equally argued however that today's maverick views are tomorrow's orthodoxy, and Evans (2002) is correct in his belief that "the challenge for all of us who understand that trees matter is to find ways of reaching that promise".

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Sustainable Development

CAN BOGOTA'S APPROACH TO STAKEHOLDER INVOLVEMENT AND SERVICE PROVISION IN SOCIAL HOUSING FOR INTERNALLY DISPLACED PERSONS INFORM SUSTAINABLE CITIES AND COMMUNITIES TARGETS?

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ABSTRACT

Bogota's 'Plaza de la Hoja' was conceived as part of the District Development Plan 2012-2016 as a pioneering public social and urban project for families displaced by the on-going civil conflict.

Constructed on a prime central lot, its approach went further than sustainable design elements, with a strategic plan for peaceful social cohabitation involving the displaced and local community. This involved a consortium of public partners, led by Metrovivienda and Bogota's Environment Agency working with the High Council for Victims' Rights to create a holistic approach towards community integration. Offices for social integration and development were constructed alongside the housing in this mixed-use development.

Social stigma surrounds victims of displacement in Colombia and this project initially generated protests from adjacent neighbourhoods. Additionally, residents of the development identified parts of the plan as incomplete at handover, as well as difficulties resourcing for maintenance and security, impeding self-management capacity. The project was jointly funded by the local and national government, who had an unstable relationship during this project, with influential media branding the plan populist and doubting impacts on social integration.

In analysing project impacts, this report first summarises data from public bodies involved at the planning stage to identify provisions made for social inclusion and community sustainability. It then elucidates how these provisions translated into practice post-handover and seeks to identify barriers, evaluating them from a critical-realist perspective to support interdisciplinary integration in terms of stakeholder involvement in the construction project. This will be used to discuss the challenges and possibilities for the Plaza de la Hoja, and how this approach to sustainability and stakeholder inclusion could inform future efforts to meet UN Sustainable Cities and Communities targets.

INTRODUCTION

Bogota's 'Plaza de la Hoja' (Leaf Square) was conceived as part of the District Development Plan 2012-2016 of Bogota City Council as a new approach for the city to publically fund social housing for 457 families displaced by civil conflict (Ministry for Housing, 2012). The project was led by public housing body Metrovivienda (Metrovivienda 2013a) with a consortium of departments such as the High Council for Victims' Rights being included at the planning stage to devise a strategy for peaceful social cohabitation for both the displaced and local community's needs (Mayor of Bogota, 2015a).

The impacts of peripheral housing in Bogota on reinforcing cycles of poverty, poor transport connections, access to employment and public services is well documented in existing literature (Torres Tovar 2009; Torres Tovar, Rincon Garcia and Vargas Moreno, 2010; Mayor of Bogota 2013), with the majority of the internally displaced relocating to these areas (CODHES, 2009; Centro de Memoria Paz y Reconciliación 2014). In Bogota this cycle has been repeated over generations with the internal conflict in Colombia continuing over sixty years (Hudson, 2010; Historic Commission for Colombian Conflict and its Victims, 2015), yet a 1998 report discovered for the 160,000-180,000 expected population increase, only 10,720 new housing units were legally constructed, with the city's housing offering to low/no-income populations focussed on slum legitimisation (Cullen-Cheung, 2004) confining the most vulnerable to the peripheries. Publically funding and placing IDPs on a prime central lot has set a precedent in the city (Mayor of Bogota, 2015b) and caused controversy (Semana, 2012; Gonzalez 2014 El Espectador 2014), with political capital waged on the success of this project (Ministry for Housing 2015; Castillo, 2015).

This report evaluates from critical realist perspective (Naess, 2015; Wardner, 2014) to create an overview of the development and delivery of a project where stakeholders were integral to its design via an analysis framework examining influences and impacts of the project through available public planning documentation, complemented by reports and interviews over the capital/delivery phase. In interpreting how service provision translated into practice, the paper seeks to identify barriers and draw on literature relating to underlying political mechanisms and social and environmental impacts of displacement in Bogota and Colombia; assessing if any key approaches to addressing service provision in vulnerable populations can inform the UN's Sustainable Development Goals (SDGs) Sustainable Cities and Communities target (UN, 2015).

PROJECT BACKGROUND: PLAZA DE LA HOJA

Project Location

Bogota is situated on a high plain centrally in the Andes mountain range. Urban growth is geographically restricted, with the city centre constructed up to the face of mountains in the east. The 'Plaza de la Hoja' is constructed on a central lot, close to public hospitals, shopping plazas, universities, and the city centre (Metrovivienda, 2013a).

Project Delivery Team

The project was led by Metrovivienda, partnered by the local environment agency *Secretaria Distrital del Ambiente* (Metrovivienda 2013a) under the Free Housing Program of the National Government (Ministry for Housing, 2012). Utilities were consulted to facilitate in waste management and educate residents in environmental sustainability. Private businesses from the adjacent shopping mall offered employment opportunities for new residents (Mayor of Bogota,

2013). *The total investment was 20.6bn Colombian Pesos (COP) (~$6,5million at 3,060COP = $1) of which the national government pledged 18.2bn COP (~$5,9million) and Bogota 2.3bn COP (~$750,000) (Ministry for Housing, 2012).*

Metrovivienda

Metrovivienda is an agency of Bogota City Council, describing itself as the real-estate manager for the district "promoting the construction of affordable housing, with the fundamental proposition of guaranteeing the most vulnerable a dignified place to live" (Metrovivienda 2013a, p5).

The High Council for Victims

Bogota's High Council for Victims, Peace and Reconciliation was created in February 2012 with the objective of communicating programs offered by the national government for victims of the armed conflict at a district level; It achieves this through a network of one-stop centres called 'Dignificar' whose direct involvement with the victims assists in identifying those most in need (Mayor of Bogota, 2012). The High Council liaises both with local government so they understand victims' needs as well as providing community liaison and practical advice for the new occupants (El Nuevo Siglo, 2015).

Definitions of the housing units, 'VIP' and 'VIS' in this project

VIP – *Vivienda interes prioritario* – Priority Housing. Distributed via a lottery, where those selected out of a group of internally displaced persons (IDPs) would receive a home under the national government's free housing scheme (High Council for the Victims, 2015).
VIS – *Vivienda interes social* – 'Social interest' or affordable housing. Optional additional 'VIS' units can be constructed in this project in order to generate further revenue. Their maximum value is limited to the equivalent of 62 minimum monthly wages (Metrovivienda 2013a).

SPECIFICATION AND DESIGN

Metrovivienda supplied a publically accessible 42-page specification to launch the project design competition on the 18th January 2013 with the winner announced on March the 15th, 2013. The judging panel consisted of architects from the Colombian Society of Architecture (Metrovivienda 2013a).

The social stipulations outlined in the proviso stated that the social character should favour creation of harmonious relationships in a way which optimises communal spaces (Metrovivienda 2013a, p13) with a minimum of 417 VIP homes and optional VIS units but that non-VIP/VIS were not permitted (Metrovivienda 2013b, p6). The solution is to offer permanent and secure housing with a desire to include accessible housing (Metrovivienda 2013a, p15). Innovation and versatility of the habitable space should offer inhabitants the opportunity of home-ownership, to put down roots and construct an identity (Metrovivienda 2013a, p17). Stipulation for environmental sustainability includes: green walls, rainwater recycling in communal facilities, low maintenance landscaping, consideration of alternative energy such as solar where cost efficient; sustainable urban drainage and bicycle parking (Metrovivienda 2013a, p17-21).

The local agency for habitat and housing (Secretaría Distrital del Hábitat) in conjunction with Metrovivienda and partners proposed stipulations for stakeholder integration pre-handover. These took the form of socio-economic assessment of the families in order to facilitate community

sustainability and meeting with the families who are going to live in the development prior to their moving and prioritise their needs. The objective is to foster a culture of peace between the new residents and surrounding community, and develop plans in areas of security, communal living, access to education, health, sports and recreation, access to employment, income generation and consolidation of the community organisation (Mayor of Bogota, 2015a).

The design competition was won by MGP Architecture and Urbanism of Bogota (Castro, 2013), who have prior experience in affordable (VIS) projects, having previously completed 5 VIS projects between 1995 & 2007 (MGP Architecture, 2016). The proposal was for a mixed used project as detailed in Figure 1.

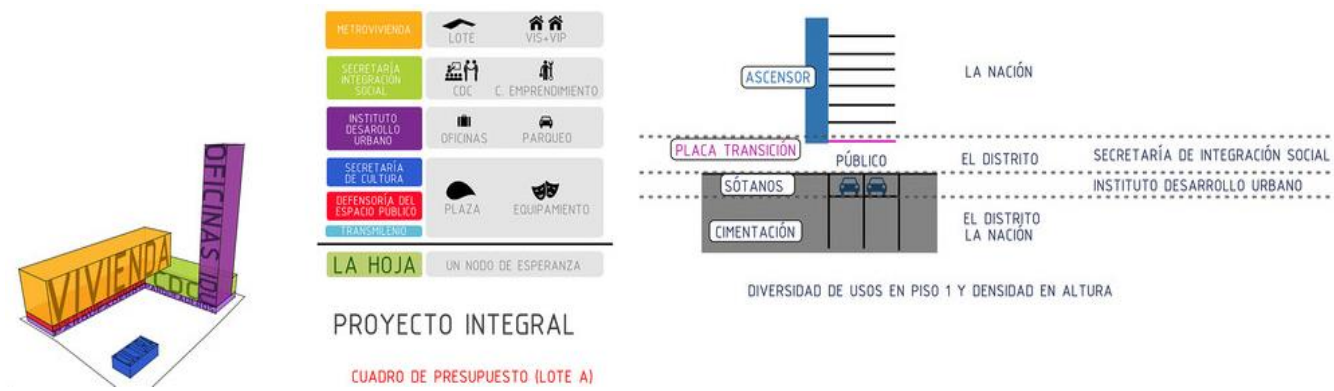

Figure 1: Extract from architectural proposal (Castro, 2013):
The mixed use development shows a medium-rise housing area for VIS and VIP housing in yellow; Agency for Social Integration in Green, and offices for the Institute of Urban Development in Purple. The ground floor is open as a public thoroughfare, with parking spaces below.

CONSTRUCTION AND HANDOVER TO OCCUPANTS

At the beginning of February 2015 the main contractor, Arpro, began the handover (Metrocuadrado, 2015), with a total of 452 apartments in towers between 5 and 12 stories high. Construction ran from February 2014 until March 2015 (Arpro, 2015). The main contractor followed suit in terms of involvement of project stakeholders, in terms of communicating laws and obligations relating to use of the communal areas despite this not being a contractual pre-requisite. Arpro stated this "reinforced the work that the Local Ministry of Social Integration and ANSPE (National Agency for Overcoming Extreme Poverty), as added value to the project that the company wants to give the community" (MetroCuadrado, 2015).

On January 23rd, Bogotá City Council assigned 361 housing units to IDPs in the centre of Bogota. Families registered as IDPs attended a lottery draw held by then Mayor Gustavo Petro and President Juan Manuel Santos to assign VIP housing under the free housing scheme (High Council for the Victims 2015). A further role in the handover was taken by the High Council for the Victims, conducting walking tours of the neighbourhood (IPES 2015) explaining the various entities available to assist in areas such as health, education, financial assistance, and support for women (El Nuevo Siglo, 2015).

PROJECT ANALYSIS

An analysis framework was used to extract economic, social, environmental and influences on the project from documentation identified in *2. Specification and Design*, complemented with reports and interviews taken prior to project handover. The influences were compiled in the Venn framework in figure 2 since these factors are mutually co-constitutive. In placing project influences in the matrix according to factor, overarching factors such as the weight of political influence could be identified comparatively.

McCourt, Batley, and McLoughlin (2013) identify a growing focus on how governance and political factors not only determine whether public services are delivered, but also the standard of where, to whom and how well. In analysing factors which influence service provision, this paper uses a critical realist approach since post-modern approaches limit the scope to cultural processes and neglect social and environmental impacts (Naess, 2015), as well as underlying political mechanisms (Wardner, 2014). In addition, the consistency and quality of empirical data restricts the possibilities of using positivist and empirical approaches without conducting original research, since Colombia's census data was last compiled in 2005 (Vega Barbosa, 2015).

In order to elucidate these findings, a similar project impact analysis (Figure 3) of reports and interviews post-handover in order to identify how well socially sustainable aspects of the project plan were delivered was undertaken identifying overarching impacts of the project as socio-economic.

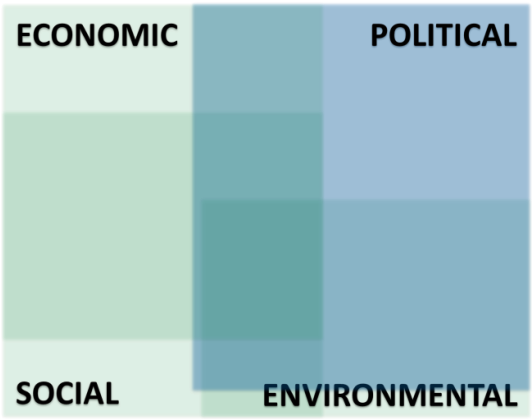

Figure 2: Diagram of analysis framework - Project influences identified

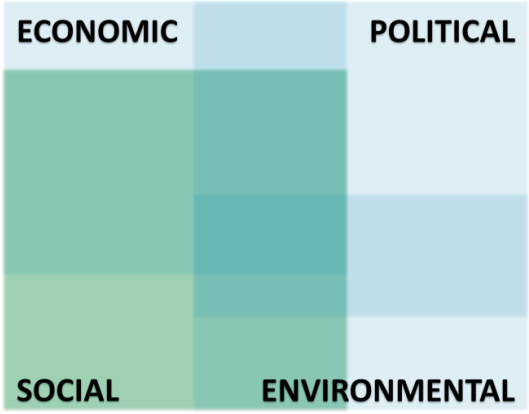

Figure 3: Diagram of analysis framework - Project impacts identified

Political, socio-economic and environmental influences on the project identified from existing literature during project capital/delivery phase (Fig. 2)

The Mayoralty depends on government funding in order to finance development of large infrastructure (Dinero, 2014), in the case of the Plaza de la Hoja, the national government funded almost 90% of the project (Ministry for Housing, 2012). The local and national government working relationship has been strained over the past two decades, with the national government occupying a Neo-Conservative position and Bogota's Mayor traditionally being a left candidate, detrimentally affecting infrastructure funding received by the capital (El Tiempo, 2009; Hudson, 2010; Dinero, 2014; Valenzuela, 2015). The then mayor was impeached by the Inspector General during this project (Yagoub, 2014; Metrovivienda 2013a), only to be reinstated after intervention of the IACHR and months of disruption and civil protest (Associated Press, 2014). Project construction occurred during the ongoing peace process in Colombia and just before a general election, and the project was critiqued as motivated to influence voters (Ministry for Housing 2015; Castillo, 2015; Mayor of Bogota, 2015a).

The changing role of Metrovivienda must also be considered since at its inception in 1998/9 Metrovivienda's principal aim was land-banking and management in a bid to control erratic development by smaller developers at Bogota's urban fringe (Ferguson and Navarrete 2003; Cullen-Cheung, 2004; Amaya, 2015). This aim was revised with Mayor Petro's election in 2012, in conjunction with changes to the city's urban master plan (Plan de Ordenamiento Territorial, POT) to focus public development of housing stock towards the centre of the city (Mayor of Bogota, 2013). In Bogota there are vast opportunities for the informal and illegal housing market (Torres Tovar, 2009), with 40-50% of the city reported to live in informal housing (Monsalve Fernandez, 2013; Cullen-Cheung, 2004). Bogota is split into 6 different social strata, with the least affluent being 1, reflecting the quality and cost of available utilities and services (Torres Tovar, 2009). Strata 1 and 2 neighbourhoods are situated around the urban periphery (Leon, 2011), going hand in hand with poor transport connections, access to employment and public services (Mayor of Bogota, 2013).

UNHCR (2015) estimates up to 5.5 million Colombians are internally displaced due to the conflict. The Colombian office for human rights and displacement (CODHES, 2009) reported government figures, critiqued as a 'partial number' for the number of displaced persons between 1997 and February 2009 as 2,935,832. with Bogota's population overall increasing officially at a rate of around 150,000 new inhabitants per year as of 2005, when it stood at 7.1 million inhabitants (District Planning Authority 2010; Colombian Institute for Urban Studies, 2005). Victims of displacement in Colombia report social stigma (National Centre for Historic Memory, 2013) with the project generating negative reactions from surrounding neighbourhoods worried about what would happen if newcomers did not find work, claiming that the IDPs would begin to steal and 'invade' their neighbourhood (Restrepo, 2013; El Espectador, 2014), protesting the development (Castillo, 2015). Secure employment is difficult to find and half of Colombians nationally are employed informally (Portafolio, 2014).

Political, socio-economic and environmental impacts of the project identified from existing literature post-handover (Fig. 3)

The high-profile nature of the project attracted a multitude of media coverage, including extensive interviews with some of the residents. Recreational and green space was identified as an overarching issue when residents first arrived, with the terraces being used by the youth as a social area which families attributed to them having nowhere else to congregate (Castillo 2015; Noticias Capital 2015a; El Tiempo 2015; El Espectador, 2015). In October, an article in El Tiempo, (2015) identified parts of the plan as incomplete such as the kindergarten and community meeting rooms, as well as insufficient financial resourcing for maintenance and security due to some residents' non-payment of the monthly 'administration fee', with other residents complaining of billing at commercial rates (Castillo, 2015), impeding the community's self-management capacity. Residents also cite concerns regarding security guards not carrying firearms and not being closed in (Castillo, 2015) with security fencing, however this could reflect the Colombian norm of gated housing (El Tiempo, 1996). Local businesses reported an upturn in trade, but divisions remain in the adjoining neighbourhood with some residents stating they won't send children to local schools due to bullying for 'victim status' (Castillo, 2015).

452 Apartments were handed over (Arpro, 2015), with 361 families drawn to receive Free Housing (High Council for the Victims 2015). As part of the free housing scheme, residents are protected from the worry of eviction on financial grounds (Castillo, 2015). Residents are better served than their previous residences in the case of mobility, access to services and location, especially in the case of disabled residents (Noticias Capital, 2015b; Metrovivienda, 2013a), and the adjacent mall is offering job opportunities to residents (Mayor of Bogota, 2015a). Physical aspects of the construction have been complimented with education: The Special Utilities Unit UAESP and Water Company of Bogotá with the development of educational processes encapsulated as part of the 'Zero Waste Program' (Mayor of Bogota, 2015a). Daytime recreation is provided in the hardstanding area but this may not be as attractive for older teens (Noticias Capital 2015a), with no permanent structures such as a 5-a-side or basketball court to keep older youths entertained in the evenings. Afro & Indigenous children's drumming groups are provided by international NGO OEI (Castillo, 2015).

Additional services came to fruition throughout the course of the year such as the opening of a new kindergarten and day centre for older people (Integración Social, 2015; Integración Social, 2016). An initiative has been launched by the new mayoralty in February 2016 dubbed 'It's all good, neighbour' (En La Buena, Vecino, 2016) to support community cohesion with a view to gathering information on how the community representative system can be improved.

Analysis of findings

In analysing the overarching influences on the project a clear theme of political motivation appeared, indicating that without an upcoming general election and the

pressure of the peace process, the national government would not have been motivated to fund a project on this scale.

One identifiable impact of the nature of the 4-year mayoral term in Bogota is the uncertainty of a political about-turn with each incoming mayor. It is important to reflect that despite inherent risks created by political instability: the mayor's impeachment, a fragile ongoing peace-process, strikes and protests and an upcoming general election (Associated Press, 2014), and that 90% of the project's funding relied on the national government, the project was still completed and handed over. This ticking time-bomb of political upheaval had an effect on the tight schedule in this project with snagging a consistent issue (Castillo, 2015) and a longer programme could have mitigated these problems. The rapid nature of construction in this project and the criticism of it being handed over without key parts of the project, such as the kindergarten being finished is less likely to do with capacity or management problems but that as a landmark project it had to be handed over before the end of the mayoral term.

Additionally, the change in scope of Metrovivienda has been beholden to changes in city hall, with its focus being adapted from land-banking to housing developer, and the possibility of its future dissolution (Cullen-Cheung, 2004; Amaya, 2015; El Espectador 2016). In January 2016, Enrique Peñalosa took over as Mayor of Bogota for the second time in its history, signifying a volte-face in the previous administration's policies; in the case of social housing, the focus is now explicitly to construct homes for the least well off and vulnerable on the peripheries (Semana, 2016). This will include the draining of swamps and destruction of wildlife habitats on the edges of the city, to accommodate this expansion (Humedales Bogota, 2016) in the areas determined by Metrovivienda to be most at risk of natural disasters (Amaya, 2015).

Despite the unstable political climate, the project impacts have been largely socio-economic, therefore despite the motivations for the scheme being largely political, benefits to residents and to the local area have been achieved and services have been delivered. Concerns in themes of security such as the security being unarmed and the development not being walled in appear to be linked to social norms (El Tiempo, 1996) suggesting a resistance to change.

In analysing 'how well' these services have been delivered it is less clear, but it is apparent that a plethora of public and private organisations have delivered different parts of the social stipulation in the proviso. The on-site office for social integration could serve residents as a 'one-stop shop', but this report alone identifies 15 different local entities involved in delivering the social stipulations set out in the proviso, an international NGO, and an additional community cohesion entity added by the new mayoralty in 2016. Rather than examining existing service providers, this approach appears to generate further entities to resolve grievances, inadvertently adding layers of bureaucracy in accessing services and accountability. This is highlighted by residents' concerns which do not seem to have been addressed over the course of the first year about the safety and suitability of the terraces as a social area (Castillo 2015; Noticias Capital 2015a; El Tiempo 2015; El Espectador, 2015).

The development's unique status as solely for VIP/VIS residents could have impacted relations between the adjacent neighbourhood of similar socio-economic status with adjoining community members commenting that "they don't live in a free house" (Castillo, 2015). The initial negative reaction from existing residents has not been fully resolved (Restrepo, 2013), and in terms of stakeholder involvement, ample resourcing was given to aid integration of IDPs (High Council for the Victims 2015; IPES 2015; El Nuevo Siglo, 2015), but less focus was made outlining the benefits the development would bring to existing communities resistant to change, despite land in this area being occupied by itinerant homeless groups prior to construction (Restrepo, 2013).

Examining social initiatives and impact on the UN Sustainable Development Goals (SDGs)

The UN (2015) 2030 Agenda for Sustainable Development Goal 11 aims to "make cities and human settlements inclusive, safe, resilient and sustainable". In tabulating the project's analysed influences and impacts, the social stipulations in the proviso principally tied in with the aims of goal 11.3: by 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.
The overarching political motivations and barriers to this project should be considered in attempts by the UN to achieve this goal. If the motivations for government funding of social housing only occur when there are large political events, then this is not a sustainable approach to human settlement planning, and attempts to deliver inclusive, participatory projects for stakeholders will remain tokenistic. The on-site agency for social integration in this mixed-use development should also be considered in similar schemes to offer a centralised approach to support and integration but further efficiencies in service provision could be achieved for the benefit of residents and service delivery alike.

Inherent political instability in Bogota is undermining a consistent approach to sustainable urbanisation and acts as a deterrent to the construction of flagship projects, in turn impeding capacity and technical experience in delivering inclusive and participatory urban projects.

CONCLUSION

For 452 families this project will have changed their lives for the better, but in analysing this project it appears that their situation will become the exception due to the volte-face in council policy to place the most vulnerable at the peripheries post-2016. The Plaza de la Hoja had the opportunity to be a precedent for similarly socially-inclusive schemes, and in terms of capacity building, lessons learned from co-ordinating social support entities could have allowed Bogota to set a benchmark in technical expertise of holistic project coordination to meet the needs of all project stakeholders. For the city itself, successfully providing centrally located large-scale housing production in the formal sector with consideration for community sustainability is imperative in the prevention of marginalisation, as well as stemming the need for informal construction with its lack of safety or services.

The aims of the physical construction have parallels with historic attempts in the Americas to re-house economically displaced populations in metropolises (McGuirk, 2015; Ferguson and Navarette 2003), and have suffered similar problems with workmanship with this large project delivered rapidly. The pioneering approach in the Colombian context has been the state taking responsibility for victims of its own civil conflict. Lessons can be learned from this project in terms of a more efficient approach to service offering, especially in the case of protracted civil conflict where re-homing without the necessary support services can lead to ghettoization of displaced and refugee populations. Making these services as accessible as possible in an unfamiliar environment is imperative, and a barrier to the success of this development is bureaucracy in coordinating the agencies intended to aid integration.

Politically, it appears that change in the scope of Metrovivienda has been used to plug holes in state service provision for low and no-income vulnerable populations, rather than the state creating a consistent strategy to take responsibility for the housing and social wellbeing of the millions of displaced. Additionally, opposition to the project was generated in the spheres of public opinion through the media who drew attention to security in the development outside of the context of location and socio-economic strata of adjoining neighbourhoods with similar social issues.

How cities manage assets and service provision more specifically in countries such as Colombia where the Washington Consensus was implemented and the bare-bones of public services remain alongside inherent political instability is something that needs to be addressed by the SDGs, so that the motivation for the state to provide services does not rely solely on quelling social unrest or the influencing of a general election.

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THE CHALLENGES THAT PROPERTY DEVELOPERS EXPERIENCE IN IMPLEMENTING GREEN BUILDING TECHNOLOGY INTO PROJECTS IN THE EASTERN CAPE, SOUTH AFRICA

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ABSTRACT

In the 21st century, people's needs with regards to their living environment differ greatly from that of the previous century and earlier societies. The reality of climate change has started a global movement to urgently reduce the amount of CO_2 emissions and to focus on the planning of environmentally friendly buildings. This shift has caused a rapid increase in the demand for a healthier and more cost-efficient living environment. Implementing green technologies or constructing green buildings is seen as a way of achieving this, but has encountered unexpected challenges. The aim of this research is to discover the challenges that property developers experience in the process of implementing buildings incorporating green technologies including, addressing the benefits derived from these buildings, both financially and in terms of health improvement. The study employed a mixed method approach involving an exploratory qualitative interview of a green building property developer followed by quantitative questionnaires, using a stratified sampling method, to collect data via an online survey of members from three Eastern Cape construction associations. Conclusions drawn are that there are many challenges that a property developer experiences with the main problem being the higher initial capital cost reducing the demand for these buildings in the Eastern Cape. Furthermore, it was found that the financial institutions providing funding and the buying public lack education on the benefits these buildings can provide, thus the additional costs are not deemed a viable investment. Recommendations include increasing the education of professionals, the financial institutions and the public on the quantifiable benefits of green buildings and the use of green technologies for projects.

INTRODUCTION

According to Feldman (2014), South Africans are increasingly conscious of the idea of 'going green', and are searching for ways to make their homes and offices more environmentally friendly. In South Africa (RSA), a three-fold increase in green buildings (GBs) has been predicted; from 16% in 2012 to 52% in 2015 (McGraw-Hill Construction, 2013). GBs are designed to be more energy and water efficient whilst they are built with non-hazardous materials, which will have the direct effect of creating and providing a healthy living environment for its occupants.

The construction industry and its final product are seen as having a significant negative impact on the environment. Construction processes affect 15% of fresh water resources, and cause up to 40% of the world's greenhouse gas emissions (GHGs) (IPCC, 2007). GBs have become a significant part of the effort to achieve sustainable development in the 21st century, so that there is a balance between long-term economic, environmental and social health activities. According to Gunnell (2009), GBs can and will significantly reduce the negative impact that conventional buildings have on the environment. A typical Leadership in Energy and Environmental Design (LEED) certified building uses 32% less electricity and reduces its annual average CO_2 emissions by 350 tons. According to Ali and Al Nsairat (2009), GBs provide the opportunity that is necessary to create environmentally efficient buildings, by using an innovative method and technique for the design, so that the negative impact of the building on the internal occupant and surrounding environment can be significantly reduced.

Ahn, Pearce and Ku (2011) believe that the GB-drive continues to change and challenge 'the construction industry to not only mitigate environmental problems and challenges associated with construction activities', but also to optimise potential economic and social benefits of incorporating GB strategies and green thinking into the built environment. Lützkendorf and Lorenz (2005) write that, from a business approach, GBs are very good financial investments whilst the operating costs of GBs are lower than that of conventional buildings. Reichard (2013) argues that the lower operating expense in GBs, compared to those of conventional buildings, will cause the rent prices to change, depending on the lease structure. Tenants who lease these properties benefit directly from savings in operating expenses. The rental income will be higher (compared to similar, less efficient buildings) because of the benefits that are derived from GB and there will be a lower running cost, which is ideal from an investment point of view as more income is generated from the GB and monthly expenses are lower. GBs are currently more expensive than conventional buildings to construct, yet the cost benefit of these buildings will be recovered from the saving in the operating costs.

Häkkinen and Belloni (2011) argue that, even though GBs require higher capital layout and costs, conventional buildings are riskier investments. Conventional buildings do not offer any hedge against climate change or high-performance features that can save on cost and that can benefit the health and productivity of the occupant. Critical to the increased development of GBs is therefore an understanding by Project Managers (PMs) of the life-cycle benefits that can accrue to the occupiers of such

buildings. Clients are often concerned about the initial costs and are reluctant to invest in GBs because they often regard the high initial costs as a risk. The construction techniques are unfamiliar to them and the lack of prior experience with these buildings generally decreases their confidence in GBs. On the other hand GBs actually create wealth in the long run from savings generated by their high-performance features (Kats *et al.,* 2010) which should boost clients' confidence in GBs. Hwang and Ng (2013) state that the PM must be able to identify the essential knowledge and skills required to be capable to deliver green construction projects. They should also be able to determine and overcome challenges encountered in managing green construction projects, as well as to determine critical knowledge areas and skills that will be needed. The most crucial challenge is designing the GB with the correct skills and knowledge, so that there is a balance of the economic, social and environmental needs at all levels of such a project.

RSA still has a long way to go to realise GB projects on a large scale as too few professionals tackle GB projects because of slow or cautious investors. There are many factors and challenges that professionals in the construction industry face, that limit the amount of GB activity in RSA. Therefore, it is critical that these challenges are identified and resolved so that GBs are the starting point for change in the RSA economy, from a carbon-driven economy to a green economy.

The potential benefits and challenges for Green Buildings

The reality of climate change has started a global movement to urgently reduce the amount of CO_2 emissions, and to focus on the planning of environmentally friendly buildings. Hwang and Tan (2010) write that GBs are created on the same principles of sustainable construction, which focuses on the ecological, social, and economic aspects of a building. These buildings are designed and built to use less energy and resources than traditional buildings; they also aim to minimise their impact on the environment. GB design and construction techniques also result in a social benefit because they enhance the occupants' comfort, health, and productivity.

Pearce and Han (2012) state that there are three major benefits of using green building technologies (GTs). Firstly, GB construction offers greater environmental benefits, compared to conventional construction methods. Applying GTs, the amount of energy and resources needed to construct and operate built facilities are reduced; the loads imposed by the built environment on the natural environment can be reduced; and the earth's finite resources can be conserved for future generations. Ross et al. (2007) have a similar view to that of Reichard (2013) in that GBs and their technologies are viewed as an effective solution to reduce the negative impact that conventional buildings have on the environment whilst reducing operating costs for the occupier. According to Silverman and Mydin (2014), by addressing energy, water, natural lighting, and natural ventilation, and accommodating the necessary technologies, the benefits of GBs can be achieved. GBs can furthermore reduce their energy consumption by 50%, compared to a conventional building. Chen and Hong (2014) claim that the building energy standards and regulations can help overcome certain market barriers and ensure cost-effective energy efficiency. It must be highlighted that these benefits are only achievable through accurate 'predictions,

confirmation that installed equipment and systems meet design specifications, and that the performance is maintained during operation'.

These environmental benefits have a direct link to the economics of a project. Yung and Chan (2012) found that the construction methods for new buildings use huge amounts of raw material and energy, and generate high rates of CO_2 emissions. Iannucci (2009) describes the financial benefit and savings created based on the improvements that green materials create in terms of energy efficiency, reduction in water use, material and waste. Additional benefits include improvements in productivity in the workplace, better health, and comfort in residential settings, reduced burdens on infrastructure, and so forth. These benefits are created due to the smart design of the building so that it may perform efficiently over the life cycle of the building, which brings continued and future benefits. According to Fletcher (2009), the user of green materials does not only influence the environment in a positive manner, but they also provide a financial benefit. GBs, with the benefits they provide, can reduce the loads imposed on centralised infrastructure thereby reducing the need to expand already strained capacity.

According to Issa et. al (2010), the main idea and driving force of GBs are to educate people, not only about the health benefits of GBs, but also the whole-life cost savings. These benefits are: Lower operation costs; lower maintenance costs; and, increased productivity and health of occupants. GBs provide substantial health benefits to occupants due to improved indoor environmental quality (IEQ). Birkenfeld *et al.*'s (2011) recent case study of IEQ and employee productivity showed that a 94% increase in air quality resulted in a 40% increase in employee productivity. The control of room temperature can increase productivity by 2%–7%; and by correcting the IEQ, productivity can increase between 13%–18%. The savings resulting from increased productivity can pay for the added technologies and equipment after one year. Furthermore, the study reported a 23%–76% reduction in acute respiratory infections among building occupants due to higher ventilation rates, reduced space-sharing, reduced occupant-density, or irradiation of air with UV light.

Kats *et al.* (2010) studied 150 conventional and green buildings in 11 countries across the world showing that GBs cost 4%–10% more than conventional buildings, depending on the design. The results showed that GBs had reduced energy-use by an average of 33% whilst energy cost-saving-calculations over a 20-year period were greater than the initial capital cost of the buildings. The calculations predicted that the amount of savings with regards to energy, water, productivity and health, worked out to be five times higher than the initial capital outlay for GBs. Bradshaw *et al.'s.* (2005) similar study of 16 residential projects in the USA supports these findings. Those results showed that 15 out of the 16 projects had lower water and energy-use costs when compared with their conventional counterparts whilst there was a 38% decrease in electricity-use, a 34% reduction on the water bill and a 35% decrease in gas cost.

Figure 1 below shows Issa *et al.'s* (2010) visual representation of the different types of predicted long-term cost savings for LEED-certified buildings. Productivity and health cost savings represent 70% of all savings in the whole-life costs in LEED-certified

and Silver buildings. Although GBs deliver significant long-term cost savings, these are hard to measure and quantify as many GBs are unique. This is the primary reason why many developers tend to ignore these buildings. Developers tend to only focus on the 12% saving in water, electricity and the 16% maintenance costs, which in turn creates a saving for the occupants in the long run.

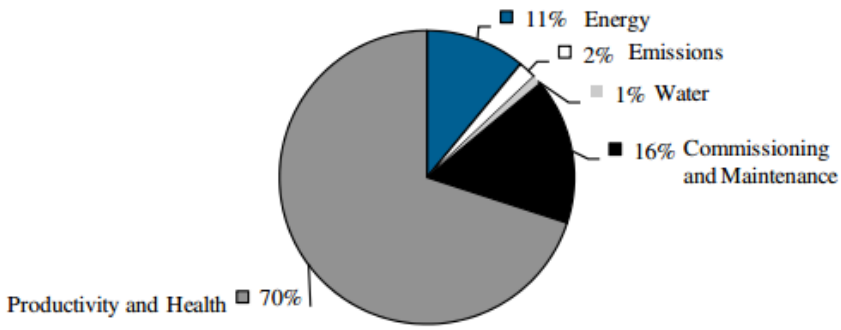

Figure 1: Productivity and Health (Issa et. al, 2010).

The use of GT and practices allow for the creation for new employment opportunities that can stimulate local economies and help to stabilise communities. To be able to improve sustainability of the built environment, new GT becomes necessary; this, in turn, creates more jobs, expands and creates new markets. New GTs for renewable energy have resulted in the growth of new manufacturing enterprises that supply these technologies to its users. Work is also created for labourers to install and maintain these systems. Ugwu and Haupt (2007) found that GT requires new education; training programmes and degrees are needed to train new workers in the green economy. GBs have created new markets for employment that are needed today as we are still in a global recession. Similarly, Hwang and Ng (2013) write that, as the GB-era continues to evolve, there will be a better understanding of the necessary characteristics of the PM to manage a green project successfully.

Key challenges and priorities for a green economy

RSA's economy is driven by cheap coal to generate electricity, which releases vast amounts of GHGs (RSA is the 14th biggest emitter of GHG in the world). In order to reduce these emissions, RSA's built environment needs to become more efficient at using electricity, as the building sector has been identified as having the largest potential for reducing greenhouse gas emissions (IPCC, 2007). However, particularly in the Eastern Cape (EC), this has not been occurring as rapidly as expected, despite a 300% increase in RSA electricity costs in the last seven years (PowerOptimal, 2015). Saladin (2013), states that this is a result of the high cost of technologies used for GBs which results in the use of cheaper alternatives. The IDC say the capital required for a greener economy has to come from the private sector. Du Plessis (2001) states that not having the financial resources available causes a shift away from using sustainable products for green construction (GC). Funds provided by the public sector would result in an increase in taxes, with a perceived negative effect on the economy.

Strietska-Ilina et al. (2011) explain that, in order to attain a green economy, a skilled workforce is needed. The RSA central policy has not focused enough on creating a greener environment and this has caused a large skills shortage. There is no coherent national strategy / policy to meet the required skills to create a green economy. Education and training authorities for green skills development are lacking. Saladin (2013) states that the green economy in RSA is vital for two main reasons: to relieve the current level of unemployment, and to reduce the high carbon impact on the economy. Hwang and Ng (2013) state that although green projects cost more than conventional projects, this additional capital cost for GB can be as little as 1%. The necessary skill to create the correct design, for the building to maximise its efficiency, and modelling cost are the primary reasons for the increase in price. This increase in additional cost often is the basis on which clients make their decision to switch to GB.

The population in Africa is expected to double from 294 million in 2000 to 742 million in 2030. 72% of the urban population currently live in slums, increasingly challenging governments to meet people's needs for sustainable human settlements with clean water and electricity. Implementing green technologies or constructing green buildings is seen as a way of achieving this but has encountered unexpected challenges particularly in the Eastern Cape. The aim of the research was thus to identify what challenges property developers experience in the process of implementing projects incorporating green technologies in order that the perceived potential benefits derived from these buildings, both financially and in terms of health improvement, can be harnessed for the betterment of a rapidly urbanising society.

RESEARCH REVIEW AND METHODOLOGY

The primary data for this study was obtained by means of a questionnaire survey with members of the Eastern Cape Master Builders Association (ECMBA), Eastern Cape Institute of Architects (ECIA) as well as local general contractors who specialise in property development. The sample stratum was selected as there is a mix between GB developers, professionals in the construction field as well as general property developers. The triangulation of the results of this research will provide a more robust outcome.

Research method

The study was conducted by the use of two techniques, conducting an investigative survey of the literature as well as conducting an empirical study using a quantitative approach. An initial semi-structured exploratory interview was undertaken with a GB property developer in order to better understand the challenges he has experienced to create two new GB developments within the Nelson Mandela Bay Metro, Eastern Cape Province. The results from this were used as the basis for the creation of a structured questionnaire using mainly five-point Likert scale type questions which was emailed to the respondents. The population sample for this study was limited to 50 members of the ECMBA, 15 local contractors in Port Elizabeth and 11 ECIA members. The ECMBA response rate was 42%, ECIA repose rate was 54.55% and the local contractor's response rate was 53.33%.

Research results

Humankind can predict and prepare for the future well-being of the ecological system. Peterson (2002) states that people use complex mental models in the designs to meet the future construction needs. People are constantly looking for new ways to update the models and provide the best possible outcome of a project. Why developers should therefore struggle to implement GB projects in the EC as opposed to RSA in general, which has emerged as a leader in GBs (Dodge Data & Analytics, 2016), formed the basis for the initial question to be answered on the variables that affect this.

Table 1, The variables that affect the amount of green building development in the Eastern Cape.

Aspect/Variable	Responses (%)							
		Minor……Major					MS	Rank
	Unsure	1	2	3	4	5	%	No.
Materials used are expensive.	0	0	0	20.58	52.94	26.47	4.05	1
The demand for these buildings is not high.	8.82	0	11.76	32.35	38.23	8.82	3.17	2
Clients are unaware of the benefits of GBs.	2.94	14.7	14.70	23.53	38.23	5.88	2.97	3
The majority of people in the Eastern Cape cannot afford these buildings.	14.70	14.7	5.88	17.64	32.35	14.70	2.82	4
A high percentage mark up on profits for these buildings which clients aren't willing to pay.	17.64	8.82	17.64	23.52	23.52	8.82	2.52	5
There is a lack of training and educational facilities in the Eastern Cape, which support GB development.	32.35	5.88	5.88	17.64	17.64	20.58	2.44	6
The site location.	11.76	20.58	17.64	26.47	20.58	2.94	2.32	7
There aren't many developers in the Eastern Cape who have the necessary skills and experience to create these. buildings.	29.41	8.82	5.88	20.58	29.41	5.8	2.29	8
Locally produced products needed for GB are unavailable.	17.64	14.70	20.58	23.52	23.52	0	2.20	9
The GB certification process is too long.	35.29	8.82	8.82	23.52	20.58	2.94	1.94	10
Banks do not give out special loans to developers to promote GB.	29.41	8.82	5.88	20.58	29.41	5.88	1.79	11

From Table 1 we can see that respondents believe the variable that most affects the amount of GB development in the EC is the use of expensive materials. This variable has a MS in the range of > 3.34 to ≤ 4.17, which indicates that it to some extent to a near major extent / near major extent affects GB development in the EC. It is noticeable that more than a quarter of respondents rated this a major variable and that there were no 'unsure' responses. In contrast to this, the 9th ranked item 'Locally produced products needed for GB are unavailable' with an MS of 2.20 would indicate that most respondents are of the opinion that local products are available and when

read with the variable that most believe affects GB development, it suggests that the respondents are aware of the price of the materials although they perceive them to be too expensive. The responses for all of the other aspects listed showed a significant proportion of 'unsure responses' as well as a significant drop in the MS, the next highest being 'The demand for these buildings aren't high' with a MS of 3.17. The big drop in the MS and the large unsure response rate aligns with the perception that there is a lack of appetite for GBs in the EC and this alongside the cost are providing a deterrent to their development.

Miller and Buys (2008) state that there is more awareness for the use of GB based on their ability to outperform conventional buildings by means of environmental, economic, and social factors. However, the choice to go ahead with such a building still presents a number of challenges to the building stakeholders, due to the insufficient information available to them about the actual performance of the building after the design phase. Understanding the variables that have the greatest influence on this decision making process will assist in better understanding the areas for future research and education of these stakeholders.

Eight out of 11 (72.72%) of the variables listed in Table 2 have MS > 3.00, which indicates that the group of respondents believe that these variables are affecting the mind-set of people when considering that they need to pay more to create GBs to major extent as opposed to minor extent for GB development is seen as ahead of its time in the EC. The respondents' beliefs that the measured variables are affecting the mind-set of people are mainly due to GB's having a higher capital cost than conventional buildings. It has a MS ranging between > 3.34 to ≤ 4.17, which indicated that it is to some extent to near major extent / near major extent affecting the mind-set of people when considering that they need to pay more to create GBs. 50% of the respondents believe that this is a major factor that contributes to affecting peoples mind set when considering these buildings.

Table 2, The variables that affect the mindset of building stakeholders when considering the need to pay more to create green buildings.

Aspect/Variable	Responses (%)							
		Minor……Major					MS	Rank
	Unsure	1	2	3	4	5	%	No.
GBs have a higher capital cost than conventional buildings.	2.94	2.94	5.88	17.64	20.58	50	4	1
GB reduce running costs.	2.94	2.94	11.76	20.58	29.41	32.35	3.68	2
Tenants are not willing to spend more to rent GBs as they do not experience the financial saving aspect of.	5.88	5.88	2.94	23.52	38.23	26.47	3.67	3
People are only willing to change if they experience the short to medium benefits of GBs.	2.94	5.88	8.82	14.70	50	17.64	3.55	4
The middle income doesn't see value in GB development.	2.94	5.88	2.94	32.35	35.29	20.58	3.52	5
GBs play a vital role in sustaining the eco-system.	2.94	11.76	11.76	14.70	26.47	32.35	3.47	6
GB development is seen as a luxurious building.	0	11.76	17.70	20.58	38.23	14.70	3.29	7
People have a conservative mindset and are afraid of change.	2.94	17.64	11.76	20.58	32.35	14.70	3.05	8
The health benefits that are derived from GBs.	8.82	8.82	14.70	26.47	23.52	17.64	3	9
The negative impact that a traditional building has on the environment.	5.88	23.52	14.70	44.11	5.88	5.88	2.38	10
GB development is seen as ahead of its time in the Eastern Cape.	23.52	8.82	26.47	23.52	8.82	8.82	2.11	11

The variables ranked 2nd to 6th namely have a MS within the range > 3.34 to ≤ 4.17 which illustrates that the respondents believe that these five variables range from some extent to near major extent / near major extent in regards to affecting the mind-set of people when considering that they need to pay more to create GBs. With regards to the above question, 17 out of the 34 (50%) of individuals that completed the questionnaire believed that to a major extent 'GB's have a higher capital cost than conventional buildings'. This shows a very definite trend in terms of the perceptions of built environment professionals.

A project's location and the demand for high-performance buildings will determine how quickly it will sell. Many customers are more interested in the purchase price instead of the long-term operating savings and therefore the price may deter people as they do not have the funds to purchase the building. Understanding these variables and the impact on decision making for the development of buildings incorporating green technologies is thus of fundamental interest. Five out of seven (71.43%) of the variables listed in Table 3 have a MSs > 3.00, with the variable ranked 1st "Annual

energy costs are lower with GBs", 2nd "Customers are unwilling to pay a higher initial capital cost on GBs" and 3rd "Cost of green technologies and materials are too high" having all attained a MS of 4 or greater. This shows that these variables have a major effect on the economic factors which influence the creation of GB's. Even the 5th ranked 'Government does not incentivise nor promote green building development' had a mean score of 3.55 with nearly 70% of respondents believing it to some extent to near major extent / near major extent affect and influence from an economic factor the creation of green buildings.

Table 3, To what extent that the following economic factors affect and influence the creation of green buildings.

Aspect/Variable	**Responses (%)**							
		Minor……Major					**MS**	**Rank**
	Unsure	**1**	**2**	**3**	**4**	**5**	**%**	**No.**
Annual energy costs are lower with GBs.	0	2.94	11.76	0	35.29	50	4.17	1
Customers are unwilling to pay a higher initial capital cost on GBs.	0	2.94	5.88	20.58	20.58	50	4.08	2
Cost of green technologies and materials are too high.	2.94	2.94	2.94	11.76	41.17	3.23	4	3
Annual water and sewerage costs are lower with GBs.	0	8.82	11.76	14.70	26.47	38.23	3.73	4
Government does not incentivise nor promote GB	8.82	11.76	2.94	5.88	32.35	38.23	3.55	5
Insurance companies do not have green building risk-specific policies	29.41	8.82	5.88	11.76	20.58	23.52	2.55	6
Banks are unwilling to give better interest rates on loans.	26.47	14.70	20.58	11.76	20.58	5.88	2.02	7

Saladin (2013) states that the green economy in RSA is vital for two main reasons: To relieve the current level of unemployment, and to reduce the high carbon impact on the economy. However, there is a perception that there is a lack of skilled workers in RSA that limits work opportunities in this sector. Better understanding of this would provide insight into to what may be limiting the potential for further GB development.

Table 4, To what extent do you believe that education and training impacts the development of the green building industry in South Africa.

Aspect/Variable	Responses (%)							
		Minor……Major					MS	Rank
	Unsure	1	2	3	4	5	%	No.
Lack of government incentive to provide free training seminars to professionals.	8.82	8.82	2.94	14.70	35.29	29.41	3.47	1
Construction companies do not have enough experience in this field.	0	8.82	17.64	23.52	23.52	26.47	3.41	2
There is a shortage of professionals and skilled workers in this field.	0	8.82	23.52	17.64	29.41	20.58	3.29	3
There are not enough education and training seminars.	0	5.88	23.52	20.58	38.23	11.76	3.26	4
There aren't enough awareness programs about GB development.	5.88	11.76	14.70	8.82	47.05	11.76	3.14	5
Tertiary education on green buildings is limited.	23.52	2.94	8.82	20.58	32.35	11.76	2.70	6
Professionals in this field leave the country after becoming qualified as there are few incentives to stay.	23.52	8.82	14.70	8.82	26.47	17.64	2.58	7
GB professionals are recruited from other countries to develop projects.	20.58	17.64	11.76	23.52	17.64	8.82	2.26	8

Five out of eight (62.5%) of the variables listed in Table 4 have a MS > 3.00 which illustrates that the group of respondents believe that the variables impacting education and training affect the development of the GB industry in RSA to a major extent. Furthermore, respondents believe that of the variables which affect education and training thereby impacting the development of the GB industry in RSA, the main aspect is due to a lack of government incentives to provide free training seminars for professionals, with this being seen to impact some extent to near major extent / near major extent. The variables ranked second through fifth all have MS in very close proximity to one another ranging from 3.41 down to 3.14 indicating that it is likely that a number of related education and training aspects impact the development of the GB industry in RSA. These include that construction companies do not have enough experience in this field, a shortage of professionals and skilled workers in this field, not enough education and training seminars and similarly and insufficient awareness programs around GB development.

DISCUSSION

The research wanted to address whether banks do not want to fund perceived additional risk linked to GBs but the evidence on this is conflicting. The empirical findings are inconclusive with the majority of the respondents 'unsure' whilst the remaining respondents considered this hypothesis to not be important to less than important. The indication is that the respondents perceived that banks that do not give out special loans to developers to promote GBs isn't a factor in the development of these projects. It was also notable that half of the architect respondents were 'unsure' with regards how financial institutions affect GBs, whilst the majority of local contractors believed this to be a major influence. The review of the related literature

is more in line with the latter belief with Du Plessis (2001) stating that not having the financial resources available causes a shift away from using sustainable products for GC whilst Koslow (2009) finds that capital availability is a major obstacle with retrofitting existing buildings. After an annual survey of 1400 building managers, the results showed that 42% of the respondents claimed capital availability was the biggest issue, followed by insufficient payback (21%). Developers do not necessarily have the additional capital required to obtain the green materials, which affects contractors more than the designers. The interview indicated that the banks are not treating green developments any differently and are not prepared to take on the additional risk that they are perceived to represent due to higher initial capital costs. The literature challenges this assumption with Lützkendorf and Lorenz (2005) stating that, from a business approach, GBs are very good financial investments and that the operating costs are lower than that of conventional buildings, therefore only the capital cost is higher, not the risk.

Part of the challenge in addressing this is that there are limited seminars for property developers in the EC to be better educated on the potential return of GBs. Respondents agreed with this to some extent to near major extent / near major extent. Although there is a higher cost attached to the creation of GBs there are the benefits of reduced maintenance and running costs. The findings show that there is a link between initial costs, ongoing running cost benefits, as well as the health benefits of GB. Tenants who lease these properties benefit directly from savings in operating expenses. Reichard (2013) argues that the lower operating expense in GBs, compared to those of conventional buildings, will cause the rent prices to change, depending on the lease structure. The sustainability and long term benefits for GB's have not been well promoted and it is the belief that more education and greater support in this field may lead to a higher demand in the field for the property developers. The rental income will be higher (compared to similar, less efficient buildings) because of the benefits that are derived from GT and there will be a lower running cost, which is ideal from an investment point of view as more income is generated from the GB against lower monthly expenses.

Respondents also believe that there are limited training facilities and courses to improve the GB knowledge of construction personnel in the EC and this is a major reason for the lack of development of these buildings in the EC. They indicated that they believe that the Government must provide more training seminars or workshops so that professionals are more equipped to handle the creation and development of these buildings. The RSA central policy has not focused enough on creating a greener environment and this has caused a knowledge shortage. Aligned to this was the assertion that as very few GBs have been constructed in the EC, there is no inherent knowledge in the local contractor workforce. Strietska-Ilina et al. (2011) explain that, in order to attain a green economy, a skilled workforce is needed. Respondents believe that there are not enough educational facilities to enhance the workforce, which provides the local contractor with many challenges to overcome without the knowledge that is needed. Currently, RSA has no coherent national strategy / policy to meet the required skills to create a green economy whilst education and training authorities for green skills development are lacking. Furthermore, the Government does not have a fund or enough capital to directly provide the skills development

programmes nationally, which are used to implement green initiatives. The review of other related literature confirms this, with studies that have verified that 'green technologies pose certain obstacles for developers, clients and contractors'. This can be as a result of 'insufficient knowledge or technical expertise and unfamiliarity with the products, materials, system, or design' but the main challenge is that 'GT are usually more complicated and are different from conventional technologies' (Zhang et al., 2011).

Finally, the assertion that clients consider only the capital cost and not the life-cycle cost was supported by respondents to a near major extent / major extent and believe the capital cost for GB is a major deciding factor when considering GBs. The hypothesis is further supported by the review of the related literature and the interview. Hwang and Ng (2013) state that green projects cost more than conventional projects with the necessary skill to create the correct design, for the building to maximise its efficiency and modelling cost, the primary reasons for the increase. Cost is often the basis upon which clients make their decision, so the additional capital cost for a GB often scares them away as they do not take into consideration the savings brought about by the included benefits. Respondents agree that there is a strong focus on the capital cost of the GB and this is more important than the health benefits that GBs produce i.e. less sick days, more productive work force. The respondents further agreed that the health benefits that are created from the GB are an important factor to take into consideration, but it is not as important as the capital cost. This, despite research by Birkenfeld et al. (2011) which concluded that improving the occupants' health in a building with more effective air filters, will result in financial benefits. The case study of IEQ and employee productivity showed that a 94% increase in air quality resulted in a 40% increase in employee productivity. Furthermore, the study reported a 23%–76% reduction in acute respiratory infections among building occupants due to higher ventilation rates, reduced space-sharing, reduced occupant-density, or irradiation of air with UV light.

CONCLUSION

After completing the study, it can be seen that there are many challenges that a property developer experiences when trying to create GBs. The empirical research concluded that the main challenge or problem with GBs is the higher capital cost. This created a reason for why there isn't a high demand for these buildings in the EC, as well as that citizens have no confidence in these buildings which further decreases the demand for GBs. It was discovered that there is a certain amount of knowledge with regards to GBs, as there was an understanding about the reduced running cost that GBs create. However, the research found that there is a lack of education in this field as people value high cost over the health benefits and running cost savings, something the literature has shown outweigh the high cost after a few years, which would justify why GBs are a good investment for property developers. Training professionals is a step in the right direction to promote GB development whilst the need for education and training seminars are critical to increase the demand as the correct information can be used to better market GBs. The government needs to be more involved with GB development, as GB is the answer to resolving the water and electricity crisis that RSA is experiencing. By incorporating GBs into the construction environment there is

a huge cost saving potential as well as relieving the pressure on water and electricity supply. Furthermore in RSA the financial institutions also need to be educated about GBs. This allows for a distinction between GBs and conventional buildings, which will support the fact that GBs are not a risk and in fact a good investment based on their ability to lower running costs. It was found that people are hesitant to move to GB as they didn't want to pay more for GBs and GTs. It is clear that GBs are the future for achieving a balance between the natural environment and the construction environment and that the benefits of GBs positively affect one's health, finances and the natural environment.

Recommendations

It is clear that GBs are the way forward to achieve a harmonious balance between the environment and the built environment. There needs to be more education and training in this field as many of the professionals in construction, especially local contractors were uneducated or uninformed regarding GB construction. In order to improve the education and training of GB's there needs to be some sort of government incentive to help encourage and foster these GBs as the benefits that are created from these buildings are of value financially as well as for the general health of the population. The research revealed that respondents were unsure about a number of aspects related to GBs which reflects poorly on professionals and would indicate an apparent lack of education in the field. The need for education on this topic will bring much needed clarity with respect to the benefits that accrue to people in these buildings. People are often scared away by the initial higher price of GB, but do not take into consideration the long-term benefits that are associated with these buildings. These technologies are generally more expensive than those of conventional technologies, so by creating an increased demand for them and manufacturing these products locally, a reduction in the price can be achieved. It is recommended that further studies should be done in order to help resolve the issues of high capital costs for these GBs by linking this to the long term savings and health benefits. Research needs to be focussed more on the life cycle benefits.

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SUSTAINABILITY SCOPE IN URBAN BUILDING DEVELOPMENTS IN LAGOS, NIGERIA

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Key Words: ISO, Lagos, Real Estate Developments, Sustainability Indicators, User Experience

ABSTRACT

The concept of 'sustainability' is one that needs no new emphasis in environmental and contemporary discourses. Embracing it not only helps to attain inter-generational equity, but also helps in achieving competitive *advantage* and value maximization. *In urban development projects, sustainability measures are best incorporated at the design stage, or alternatively retrofitted during the project life. This paper attempts to assess the scope of sustainability in the design and/or structure of various urban real estate developments in Lagos, Nigeria, through the use of primary data elicited specifically for the study. The methodology involves a survey of selected scientific literature, which assesses various sustainability indicators incorporated into the design and management of real estate developments under survey, in order to present the altitude of discussions on the subject matter of this research. This is backed up with primary data, analysed using a relative importance score index/ ranking method, adopting and adapting from key and relevant components under the International Organization for Standardization (ISO) standards - ISO 21929-1:2011. In this regard, it focuses on real estate developments against the backdrop of 'energy' 'financial' and 'social' sustainability requirements within the context of the experiences of users. It is concluded that the potentials inherent at the design/structural arrangement of these real estate projects are not appropriately nor adequately harnessed – in spite of the ever-increasing need for the sustainability. Also, social considerations are lacking in scope. Recommendations are therefore made - based on the loopholes identified. As such, relevant urban development key players and regulatory authorities may need to contextually re-focus their attention on optimal resource management through sound sustainability measures.*

INTRODUCTION

The incorporation of sustainability features in real estate development projects is becoming increasingly germane, as it stimulates reduced costs of development and use by maximizing value, promoting public and environmental health, and minimizing wastages through efficient and innovative measures. The manner in which structures are built, operated and maintained, have a tremendous impact on the environment, and on the wellbeing of building users.

The requirements for efficient resource use and environmental protection, as key contributors in regional economies and communities, dictate necessary adjustments to be taken by real estate developers. To this end, the principles of sustainability have become particularly important over the past decade in real estate/ building developments. According to Otegbulu (2011), in Nigeria, in spite of the huge environmental and energy problems, designers have not seen the need for a shift from their traditional method of designing buildings. Essentially it appears that little or no systematic attention is given to sustainability features in the region. This constitutes the major focus of this study and is expatiated on below.

From scientific literature, it can be seen that there is a three-fold framework within the scope of sustainable development of real estate, namely: (a) *Economics of Resource Use*, which includes the dynamics of value maximization, like costs of development and use/operating expenses. (b) *Environmental and Ecological sustainability* which reduces greenhouse emissions, promotes ecological balances/public health etc, and (c) *Social considerations*, by way of attitudes and dispositions, awareness levels, levels of public interest, social inclusiveness etc.

In terms of 'Environmental and Ecological sustainability', Otegbulu (2011) explains that energy efficiency, water efficiency, waste reduction, building operation, construction, maintenance, occupant health and productivity, storm water management, climate and environmental integration (Sustainable neighbourhoods), real estate and environmental interactions are all included under this framework. Further, sustainability characteristics overlap with many other neighbourhood elements like storm water infrastructure and the use of vegetation in neighbourhood design. For example, trees shade buildings and shield them from wind while green roof buildings may both reduce storm water runoff and provide evaporative cooling.

Within the scope of 'Social Considerations', in Guofeng and Jingjing (2011), when awareness reaches a certain stage, the ecology direction of sustainable development becomes more apparent. Social concerns in real estate development sustainability are therefore equally as important, and not secondary to other sustainability issues.

Based on this framework, the scope of these indicators, were evaluated in selected scientific literature focusing on Lagos, Nigeria. However not all studies in real estate development sustainability touch all these three indicators. Therefore, each study surveyed was only reviewed within the extent to which it 'covered' the three major sustainability indicators mentioned above.

The aim of the study therefore is to determine the extent to which buildings in the study area exhibit characteristics that are green or sustainable. By so doing, the various sub-indicators of sustainability in buildings are also ranked in order or 'performance'. The justification for a study of this nature is that it contributes to scientific discourses providing proper insight as to building sustainability in developing countries. Further, it highlights areas for real estate development sustainability 'reform' in the urban environment, and also helps ease decisions by potential investors. The ISO (International Organization for Standardization, 2011) explains that sustainability indicators for construction works are required by a number of parties interested in the building and construction sector in decision-making by developers and owners of buildings, designers, contractors, administrative bodies, users and property managers. Further, it is explained that the building and construction sector requires sustainability indicators both for its own decision-making within design, production and management of buildings, as well as for indicating to the public and to clients the overall economic, environmental or social impact of buildings, building products and related processes. According to Parsa and Farshchi (1996), the property development process lies at the heart of the production of the built environment, thus having the greatest impact on the natural environment. With the increased concern about the environment, much pressure is being exerted on the real estate industry to take more account of sustainability.

This section provides the aim and justification of the study. The next section reviews selected relevant literature, encapsulating the major points under review, with a focus on arriving at necessary conclusions towards fulfilling the aim of study. Though there is a dearth of literature on the specific focus of this study, the studies surveyed shows the extent of work carried out in this regard. In the final section, the lessons learned as well as recommendations are put forth in the concluding section.

SURVEY OF LITERATURE

The scope of sustainability in real estate development is well defined in literature. This section aims to determine the extent to which this scope is embraced in Nigeria. The subject matter of this study appeared rather lacking in literature in the study area. As such, the use of primary data from a field survey was elicited for a more meaningful study.

Otegbulu (2011) looked at the 'economics of resource use' and 'social considerations' in real estate development sustainability - as defined within the scope of this study. With the former, storm-water infrastructure in real estate developments' sustainability features were considered. This was carried out by determining the economic implications of the effect of poor green design on environmental sustainability, and also by determining the level of green design element appreciation of occupiers through their value hierarchy preferences of building services/components. It is reported that conventional construction methods in Nigeria do not take sustainability into consideration and are not environmentally friendly, thereby failing to attain social and economic considerations in sustainability. Using a fact finding survey on metropolitan Lagos – Nigeria, and targeting only

residential households in the study area, findings revealed that flooding constrained movement and caused delays in vehicular and pedestrian movement which leads to loss of productive man hours. In terms of man-hours, it was reported that residents lose 2,205 and 2,402 respectively (for households in duplexes and flats) each time there is heavy rainfall. The average duration for storm water to drain after heavy rainfall is 2.56 days and 4 days – respectively. The prolonged period of the flood could affect the building fabric and increase damage to furniture. The total cost of flood related damages arising from poor sustainability features was but at on their asset is N338,248,755. These costs incurred are potentially completely avoidable.

Under the scope of 'social considerations', it was found that ventilation and natural lighting are not very high in households' rankings as they ranked 5th and 7th respectively, and this is an indication of how low households perceive the importance of green and sustainable design in a tropical climate like Nigeria. It is rather surprising that in a highly tropical and humid climate like Nigeria, coupled with the deplorable power situation, such considerations under real estate sustainability reveal such statistics.

Nduka and Sotunbo (2014), investigated construction professionals' perceptions on the awareness (social considerations/ indicators) of the green building rating system and the accruable benefits in construction projects in Nigeria. The study objectives included an assessment of the awareness of green building rating systems (social considerations) as well as the most preferred rating system for possible adoption in Nigeria. The research process entailed the use of questionnaires that were designed to elicit information on respondents' views on issues such as the awareness/knowledge base of green building rating systems and the most preferred rating system for possible adoption, perceived benefits to adopt green building concepts in construction projects in Nigeria among others. The study area was Lagos, Nigeria and the study population constituted construction industry professionals. Findings suggested that 61% of the study population (based on respondents) were aware and also had knowledge of Leadership in Energy and Environmental Design (LEED), 47% of the respondents are aware of the building research establishment's environmental assessment method (BREEAM), 33% of the respondents are aware of comprehensive assessment system for building environmental efficiency (CASBEE), 27% of the respondents are aware of green globes while 22% of the respondents for Green homes (IGBC) and the least of 20% are aware of Green Star. According to the authors, these results suggest that most of the building industry professionals in Nigeria are familiar with identified green building rating systems.

In Nduka and Sotunbo's (2014), and Otegbulu (2011), it is suggested that stakeholders at all levels require an urgent and effective large scale capacity building and awareness program, including technical knowledge needed to deliver solutions. Though Otegbulu's study did not show respondent's characteristics, a generalization can be made on an aggregated basis. It can be expected that a study population based on the socio-economic profile of the location of the dwellings under study, will consist of a mix of individuals/respondents with varying educational backgrounds, while those in the formal construction sector could be regarded 'educated' on an aggregated scale.

Otegbulu and Adewunmi (2009) aimed to determine the sustainability of housing development in the context of neighbourhood infrastructure provision and also to examine the level of averting cost and substitutes resorted to by households in the study areas. This fell contextually within the scope of 'economics of sustainability' in housing. The findings of the survey, which was carried out in two residential areas in Lagos, Nigeria are clear on the economic impact of poor infrastructure provision on households in the study areas for sustainability. According to the authors, in effect, when necessary infrastructure for work is constrained, household productivity declines with low consequential economic capacity. This in effect affects their ability to pay rent, or maintain the buildings in a sustainable manner. Poor water conditions are a guarantee for poor sanitation in homes. The study essentially shows that housing development in the area lacks sustainability due to poor infrastructure conditions.

Nwokoro and Onukwube (2011), examined major concepts under sustainable construction (social, economic, biophysical and technical) in understanding sustainable and green construction as well as practices and challenges of sustainable construction in Lagos, Nigeria. The study adopted the use of both quantitative and qualitative methods of primary data collection and was sourced from professionals in the construction industry, contractors, developers and clients. The data collection instrument was the structured questionnaire, eliciting information on how social, economic, bio- physical and technical indicators facilitate sustainable construction. Findings revealed that social factors that were ranked highly by respondents within the scope of construction sustainability.

This brief literature essentially reveals the low levels of sustainability in building developments in the region. However, little or no attention is placed on the rankings/ level of performance of the sub-indicators of sustainability.

RESEARCH PROCESS AND STUDY AREA

As mentioned in the first section of this paper, the aim of the study is to determine the extent to which buildings in the study area exhibit characteristics that are green or sustainable. The survey of literature was ultimately found inadequate to make significant judgements and conclusions. Given the scope of sustainability as discussed in the first section of this paper, the data collection instrument (structured questionnaires) was designed in line with the aim of eliciting primary data within this context. The study area focused on Yaba Local Council Development Area - a major geographical and administrative fragment of Mainland Local Government in Lagos, Nigeria - due to the diverse socio-economic profile of building occupants in the region. This was found particularly necessary in order not to elicit skewed or invalid results, and make reasonable inferences about Lagos. Also, as mentioned in the abstract of the study, the ISO standards were used as a benchmark for assessing sustainability in building developments in the study area. The ISO was particularly adopted due to its apparent reliability as derived from a qualitative process. The standards are developed through a consensus process by experts from all over the world, reflecting a wealth of international experience and knowledge (ISO, 2011). Essentially, the standards

establish a core set of indicators to be taken into account in the use and development of sustainability indicators for assessing the sustainability performance of new or existing buildings.

A simple relative importance index was used in analysing the data so collected, and a simple Likert scale was used in the questionnaires to draw relevant information. The next section presents the results. The indices in making inferences were derived from literature, based on the broad scope of real estate development sustainability.

RESULTS

Table 1 below presents the results of the research. Physical observations were made and also supplemented with the 'report' of building occupiers concerning their experiences, in rating the scope of various green design/sustainability indices about their built environment. A 5-point ordinal scale where '1' represented 'Very inadequately incorporated', '2' represented 'Inadequately incorporated', 3 represented 'Fairly adequate', 4 represented 'Adequate' and 5 representing 'Very adequate' was used. For social considerations which looked more into sustainability indicators from the building user's perspective and attitude, the coding used was '1' to represent 'Very Low', 2 'Low' , 3 'Average', 4 'High', 5 'Very High'.

In the table below, the various considerations are presented in the first column with their sub-indicators listed. The second column 'N' represents the number of observations. The third and fourth columns represent the 'Minimum' and 'Maximum' values respectively - as assigned in the ordinal scale used. The sub-indicators were adopted from the ISO standard and scientific literature and were adapted to the study area. Under 'Environmental and Ecological Sustainability' for example, various indicators as 'analogies' under the scope of 'Environmental Impact Assessment – indoor environment' were listed. A total of 16 sub-indicators were derived as can be seen below.

Sustainability Considerations in Buildings	Sub Indicators	N	Min.	Max.	Degree of Incorporation of Sustainability Features	Ranking of Factors
Economics of Resource Use	Durability of floor finishes	206	1	5	0.8707	2
	Maintenance sustainability of internal walls (Maintainability)	215	1	5	0.7920	4
	Space Adaptability	215			0.4781	13
	Maintenance sustainability of external walls	215	1	5	0.6200	7
	Accessibility to outdoor/ neighbourhood services	215	1	5	0.4786	12
	Accessibility relating to mobility specific user requirements	211	1	5	0.5001	11
	Adaptability (Maintainability)	214	1	5	0.3575	16
Environmental and Ecological sustainability	Day Light access	215	1	5	0.6201	6
	Indoor temperature/ Thermal insulation	215	1	5	0.7133	5
	Indoor Air Quality	210	1		0.3999	15
	Energy Consumption Outlets (e.g use of energy savings light bulbs)	215	1	5	0.8755	1
	Acoustic Comfort	195	1	5	0.8313	3
	Proper Channelling of waste substances	210	1	5	0.5095	10
	Visual Comfort	211	1	5	0.4176	14
Social Considerations	Knowledge about the use of sustainable and green features in buildings	209	1	5	0.5799	8
	Commitment to green design and sustainability	212	1	5	0.5727	9

From the table above, it can be seen that the sustainability-sub indicator in buildings with the greatest display of sustainability/ green design characteristics was found to be 'Energy consumption' with a mean item score of 0.8755 (ranking highest). 'Indoor Air Quality' and Adaptability (maintainability) appeared to rank the least with mean item scores of 0.3999 and 0.3575 respectively. This supports Otegbulu's (2011) study especially in the area of design.

Conclusion and Recommendations

A major observation is that levels of education and being in the formal sector seemed to correlate with level of awareness as social considerations in real estate development sustainability. Essentially however, the perfect evidence of a sustainable building is that it can safeguard the overall wellbeing on a long-term basis. This is the main interest of stakeholders within sustainable buildings.
Most of the studies surveyed tilted towards the fact that the social consideration of sustainability in real estate development in Lagos Nigeria is a less dominant scope of sustainability. For example, the high level of awareness recorded in Nduka and Sotunbo's appears not to be inconsonance with the results of this study. This could be due to the sample characteristics. Though Otegbulu did not show respondent's characteristics in his study, a generalization can be made on an aggregated basis. The social consideration aspect of sustainability therefore requires much attention for development, as well as indoor adaptability generally (from results in the table above). The potentials inherent at the design/structural arrangement of these projects are not appropriately nor adequately harnessed, in spite of the ever-increasing need for the sustainability; however, the retrofit of green and sustainable features can be incorporated into existing buildings. In the development of projects from the onset, special consideration should be given to green design and sustainability features - given the growing level of awareness globally.

Also, the political will of governing authorities and technical know-how in industry, obviously must be firmly in place in order to attain the other concept of sustainability and green design in real estate developments. For example, all kinds of can be built or refurbished with green features. The viability and necessity of green design and sustainability is more evident when the nonchalant (do-nothing) approach is adopted.

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Sustainable Governance, Business and Enterprise

“A BELIEF RULE-BASED ENVIRONMENTAL RESPONSIBILITY ASSESSMENT SYSTEM FOR SMALL AND MEDIUM-SIZED ENTERPRISES”

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Keywords: Belief Rule-Based, Knowledge Based System, Green ICT assessment, SMEs, Environmental Responsibility, Environmental Impact Assessment, Sustainability, Reasoning with Uncertainty.

ABSTRACT

Various environmental management systems, standards and tools are being created to assist companies to become more environmental friendly. However, not all the enterprises have adopted environmental policies in the same scale and range. Additionally, there is no existing guide to help them determine their level of environmental responsibility and subsequently, provide support to enable them to move forward towards environmental responsibility excellence. This research proposes the use of a Belief Rule-Based approach to assess an enterprise’s level commitment to environmental issues. The Environmental Responsibility BRB assessment system has been developed for this research. Participating companies will have to complete a structured questionnaire. An automated analysis of their responses (using the Belief Rule-Based approach) will determine their environmental responsibility level. This is followed by a recommendation on how to progress to the next level. The recommended best practices will help promote understanding, increase awareness, and make the organization greener.

BRB systems consist of two parts: Knowledge Base and Inference Engine, which are used to derive valid conclusions from rules, established by experts with domain-specific knowledge. The knowledge base in this research is primarily guided by the EU Draft Background Report for the development of an EMAS Sectoral Reference Document on "Best Environmental Management Practice in the Telecommunications and ICT Services Sector".

The reasoning algorithm of a selected Drools JBoss BRB inference engine is forward chaining. However, the forward chaining mechanism is not equipped with uncertainty handling. Therefore, a decision is made to deploy an evidential reasoning and forward chaining with a hybrid knowledge representation inference scheme to accommodate imprecision, ambiguity and fuzzy types of uncertainties. It is believed that such a system generates well balanced, sensible and Green ICT readiness adapted results, to help enterprises focus on making improvements on more sustainable business operations.

INTRODUCTION

Companies nowadays, seem to show an increasing commitment to more sustainable behavior. Environmental responsibility is one of the pillars of a broader Corporate Social Responsibility term. The European Commission has previously defined Corporate Social Responsibility (CSR) as "a concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with their stakeholders on a voluntary basis" (Crane, Matten et al. 2013). Starting from the early 90s, due to legislation and community pressure, companies began to initiate environmental management campaigns.

Recommendations in Smart 2020 report (The Climate Group 2008) promote ICT infrastructure deployment to mitigate the pollution, waste, energy usage, etc. Undoubtedly, the ICT sector offers many applications that can bring numerous positive impacts for the natural environment. Some of them are: information, digitization, transport dematerialization, or warehouse and office space reduction (Martinuzzi, Kudlak et al. 2011). The environmental impacts of ICT largely depend on how ICT applications perform and also human energy consumption behaviour.

Due to legislation pressure and increase of community awareness, a variety of environmental management systems, standards and tools are being developed and used in order to assist companies to become more environmental friendly. Each of them has its own particular benefits and advantages, but there is no indication of which of them is better for the company's current state. The primary focus of an enterprise's environmental management depends on which industrial sector it is in. Companies might take a proactive approach to implementing environmental practices based on specific ISO standards relevant to their industry in order to reduce the environmental impact of their activities. Nevertheless, this research concentrates on a more generic and aggregated perspective of defining the environmental responsibility of a company.

How to measure the Environmental Responsibility level of SMEs? Which is the recommending path that companies should follow towards environmental performance excellence? This research addresses these questions. Therefore, the research aim primarily focuses on the development of a novel assessment and decision support model to help companies evaluate their current state followed by recommendations of behavioural and operational best practices to enhance their environmental responsibility level.

LITERATURE REVIEW

Various evaluation approaches and models for the assessment of companies' environmental impact have evolved: (Hankel, Oud et al. 2014; Industrial Research Institute 2014; Swiss Informatics Society and Green IT Special Interest Group 2015; UK HM Government 2013; Molla, Cooper et al. 2011; S. deMonsabert, K. Odeh et al. 2012). Such approaches and models help raise organizations' environmental awareness. Table 1 shows the description, analyses, and comparison amongst these models and frameworks which leads to research gap identification.

Table 1 - Maturity models comparative analysis

Framework	Goal	Assessment format	Advantages	Discrepancies for SMEs
SURF Green ICT Maturity Model	Maturity model dedicated to higher education institutions and organizations	Self-scan, .xlsx format, no external auditors	3 main sections with 6 dimensions each reflecting practical applicability in organization	Total scores calculated by mean averages and no weighting for categories
Sustainability Maturity Model, from IRI	maturity model assessment to integrate sustainability in new products development	Self-scan, .xlsx format, no external auditors	Specific for NPD, specifies key behavior practices at each level of maturity	Specific for new product development types of enterprises
Sustainability Management Maturity Model, FairRidge Group	Infrastructure management capability assessment to address sustainability challenges for companies	Request for an assessment	Experience: one of the pioneers in sustainability integration from 2009	Commercial service, not open-source
Fachgruppe Green IT	To assist large, medium and small sized enterprises, data centers and individuals in ICT domain to check their sustainability level, using guidelines and checklists, action plans	Self-scan, web-based, no external auditors	Enterprises classification; gaps identification through checklist; action list, estimating efforts and corresponding benefits	Assessment on checklist doesn't assign or identify current stage or level of an organization
UK HM Government Green ICT Maturity Model	Provides the means for governments to demonstrate the Green ICT activities adoption into business processes and operations	Self-scan, .xlsx format, no external auditors involved	Highlights business and behavioural actions to meet governmental targets in greening	Relevant only for UK public sector organizations
Green IT Readiness Framework	Helps organizations to evaluate their maturity on	Research type project, no external auditors involved	Focus on Greening of ICT, 5 standard domains with values range [0...7]	Main strength is for academia to establish cause and effect

	their "G-readiness" level, used as a decision support tool			relationships in Green ICT
SustainaBits Framework and Rating System for Sustainable IT	Provides an industry and research accepted framework to guide organizations within the IT sector to adopt sustainability policies	Research type project, no external auditors involved	A broad set of Criteria, targeted on benchmarking IT organizations	Not an assessment framework, limited to IT industry related organizations

Works dedicated to data centers assessment and greening operations have been intentionally excluded. Most of the models surveyed are research related models which require minimum knowledge on Green ICT domain and are in formats of scientific works, tables and publications or are abstract and conceptual (Molla, Cooper et al. 2011; S. deMonsabert, K. Odeh et al. 2012), mitigating the chances to be adopted by non-academic organizations. Some models (Hankel, Oud et al. 2014; Industrial Research Institute 2014) include an actual assessment by assigning scores per categories, but are not applicable for small and medium-sized enterprises. Most of the specific models focus on eliminating negative impacts of ICT infrastructure, while SMEs need a simple, comprehensive, easy to use and access tool for an assessment of their level of environmental responsibility, which probably has to incorporate strong points of systems described above ("Advantages" column).

It is evident from literature review that enterprises level Green ICT and ICT for Greening domain fundamentals need a proper classification and standardization, recognized both by industry and academia. Categorization inconsistencies are demonstrated in models above, and expected to be even more diversified among those which were not identified, skipped or missed. Also, assessment systems miss qualitative reviews and adaptations towards targeted user groups (Swiss Informatics Society and Green IT Special Interest Group 2015; UK HM Government 2013; Molla, Cooper et al. 2011). Environmental responsibility level assessment is a multi-dimensional, observational process that requires a more rigorous reasoning approach to handle uncertainties, imprecisions and at the same time, be positive perspective oriented.

Environmentally Responsibility assessment is characterized by a number of identified factors which are qualitative in nature and can be assessed based on human judgment. Thus, a general ER assessment problem for SMEs could be addressed without a detailed and rigorous audit conducted by affiliated authorities. Such an approach would be able to handle uncertainties, vagueness and fuzziness. Assessment models presented in Table 1 follow mostly traditional approaches in Green readiness assessment and reasoning, which are incapable of producing accurate ER level results. Expert systems are widely used to deal with knowledge-based decision support systems. Thus, the Belief Rule-Based approach with its ability to infer uncertain knowledge in the domain of Environmentally Responsibility has been applied in this research. Rule engines have great potential in reducing application maintenance cost,

because reasoning makes a clear separation between the logic and data, i.e. separating the application source code (not modified) from the logic code (modified if logic is changed).

RESEARCH METHODOLOGY

BRB inference reasoning

Belief Rule-Based Expert Systems consist of two parts: Knowledge Base and Inference Engine, which are used to derive conclusions from rules, either established by experts with domain-specific knowledge, historical data or observation facts provided by users (Yang et al. 2006; Yang et al. 2011; Chen et al. 2015). An Inference Engine is a core algorithm of a Belief Rule-Based (BRB) system and the following section will examine available reasoning patterns to justify the selection of forward and backward chaining inference for the rule-based engine. Rule engines have great potential in reducing application maintenance cost, because reasoning makes a clear separation between the logic and data, i.e. separating the application source code (not modified) from the logic code (modified if logic is changed).

First step in building knowledge base of a BRB system is to identify relevant 1) antecedent attributes, 2) types of uncertainties and 3) corresponding weights. These in turn form a generic domain knowledge representation scheme using a belief structure (Yang et al. 2006).

Belief rule-based schema is defined as follows:

$$\begin{gathered} IF\ x_1\ is\ A_1^k \wedge x_2\ is\ A_2^k \wedge \ldots \wedge x_{Tk} is A_{Tk}^k, \\ THEN\ \{(D_1, \beta_{1,k}), (D_2, \beta_{2,k}) \ldots (D_n, \beta_{n,k}),\} \\ where\ \sum_{n=1}^{N} \beta_{n,k} \leq 1 \end{gathered} \tag{1}$$

with a rule weight θ_k and attribute weight $\delta_{1,k}, \delta_{2,k} \ldots \delta_{Tk,k}, k \in \{1 \ldots L\}$.

Here, $x_1, x_2 \ldots x_{1Tk}$ denote the antecedent variables in the k_{th}rule. These attributes belong to the set of antecedent variables $X = \{x_i; i = 1 \ldots T\}$ in which each element takes a value from an array of finite sets $A = \{A_1 \ldots A_t\}$. The vector $A_i = \{A_{i,n}: n = 1 \ldots N_i = |A_i|\}$ is defined as the set of referential attributes for antecedent variable x_i. In the k_{th} rule, A_i^k represents the referential value corresponding to i_{th} antecedent variable. T_k denotes the total number of antecedent attributes in the k_{th} rule; $\beta_{n,k}$is a belief degree to which D_n is assumed to be consequent, taking into account the logical relationship of the k_{th} rule:

$$Fk:\ x_1\ is\ A_1^k \wedge x_2\ is\ A_2^k \wedge \ldots \wedge x_{Tk} is A_{Tk}^k \tag{2}$$

If $\sum_{n=1}^{N} \beta_{n,k} = 1$ the k_{th} rule is said to be complete and incomplete otherwise (Yang et al. 2006).

For example in the case for ER assessment:

R_k: *IF the use of ecolabelled equipment is **high** and switch-off unused devices and standby policy is **medium** and standards compliant strategy adoption is **high**, THEN ER level is {(good, 0.7), (average, 0.2), (fair, 0.1), (poor, 0)},* (3)

where belief distribution representation for ER is considered good with 70 % confidence, 20% for average and 10% sure that ER level is fair. In this belief rule, the

total degree is 0.7+0.2+0.1=1, so that the assessment is complete (Yang et al. 2006). The total degree $\alpha_k$with input match of A^k antecedent in the k_{th} rule is calculated by:

$$\alpha_k = \varphi((\delta_{k1}, \alpha_{k1}) \dots (\delta_{kT_k}, \alpha_{Tk}^k)) \quad (4)$$

where φ is an aggregation function for T_k antecedents in k_{th} rule and $\delta_{k_1}(i = 1 \dots Tk)$is the weight of the i_{th} antecedent variable. An aggregation function for subjective probabilities generation is "∧" operator, i.e $\varphi_{sum}(a, b) = a + b - ab$ (Yang et al. 2011). Particularly, the consequent part of a rule is true, if only all antecedent variable meet rule conditions, so following weighted multiplicative aggregation function was used:

$$\alpha_k = \prod_{i-1}^{T_k} (\alpha_i^k)^{\overline{\delta_{ki}}}$$
$$where\ \overline{\delta_{ki}} = \frac{\delta_{ki}}{max_{i=1\dots Tk}\{\delta_{ki}\}} \quad (5)$$

Assuming that $u(D_j)$ is the utility of an individual consequent variable, single value converted result is equal to:

$$u(S(A^*)) = \sum_{j=1}^{N} u(D_j)\beta_j \quad (6)$$

The overall belief degrees are measured by individual antecedent degrees of the k_{th} rule activated by an input which is a building base for the overall output belief degree.

Knowledge Base in ER

As it is mentioned earlier, knowledge base in belief rule-based systems is either established by experts with domain-specific knowledge, historical data or observation facts or statistics. In this research, it is based on an in-depth literature review. The concept of ER is characterized with a number of identified factors, which are qualitative and quantitative in nature. Nevertheless, the main components of a company's sustainable business practices are as presented in Table 2. Categories 1-3 are dedicated to equipment procurement, management and monitoring, whereas Categories 4-5 cover equipment disposal and social impact of a sustainable behaviors among employees. Here, V_j denotes the category, e.g. V1 - Equipment procurement compliant with Green ICT guidelines and the optimization of enterprise operations.

Table 2 – KB structure

Category	Antecedents
V1: Equipment procurement compliance with Green ICT guidelines	$A^1_{1,}A^1_{2,}A^1_{3,}A^1_{4,}A^1_{5,}$
V2: Energy performance improvement and monitoring	$A^2_{1,}A^2_{2,}A^2_{3,}A^2_{4,}$
V3: Energy aware networks engineering adherence	$A^3_{1,}A^3_{2,}A^3_{3,}$
V4:Social commitment	$A^4_{1,}A^4_{2,}A^4_{3,}A^4_{4,}$
V5:Waste management	$A^5_{1,}A^5_{2}$

Knowledge base consists of 5 V_j parent categories and 17 A_j^i antecedent attributes. Each category consists of antecedent attributes that compose a set of questionnaire items that the user will need to answer. In order to provide mathematical handling of various input data types and uncertainties handling, a set of available referential values is described as {(High, 0.0), (Medium, 0.0), (Low, 0.0)}. It is important to mention that the research has followed several iterations in refining knowledge base categorization: initially there were 8 independent parent categories, which were leading to 3^8 = 6561 cases of combinations to consider, adding additional complications and overhead. That has been later merged into 5 categories for simplicity and integrity purposes. The consequent is calculated based on antecedent and referential value pairs, using Equation 1. A_j^i in Figure 1 represents corresponding questionnaire item used for the calculation of per-category V_j category. The total ER index is aggregated using the per-category breakdown values using the Equation 6.

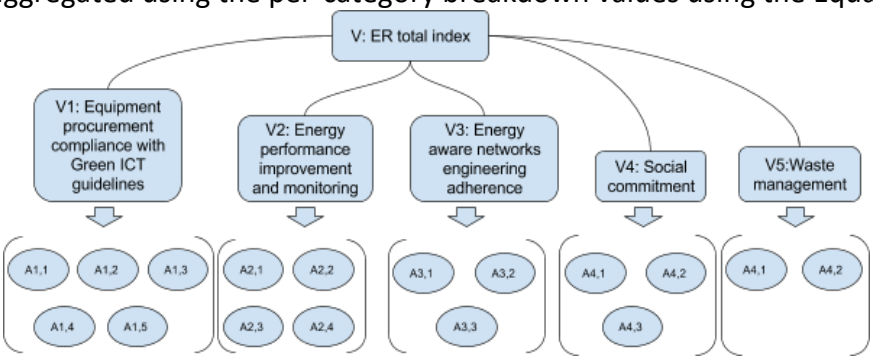

Figure 1 - Knowledge base tree

Having 5 antecedent parent categories with 3 referential values 243 total number of rules was obtained. A total number of 243 rules is determined based on the number of categories $X = \{x_i; i = 1 \dots T\}, where\ T = 5$ and 3 referential attributed (high, medium, low): $3^5 = 243$. To enumerate all possible combinations R language for statistical computing and graphics was used (function - expand.grid(1:3,1:3,1:3,1:3,1:3). Below is the extract of a matrix with 243 rules of inference:

Table 3 - Rule base matrix

Rule id	Rule weight	IF	THEN
1	1	V_1 is H & V_2 is H & V_3 is H & V_4 is H & V_5 is H	V is {H} or V is {(H, 1.0), (M, 0.0), (L, 0.0)}
2	1	V_1 is M & V_2 is H & V_3 is H & V_4 is H & V_5 is H	V is {H} or V is {(H, 0.9), (M, 0.1), (L, 0.0)}
3	1	V_1 is L & V_2 is H & V_3 is H & V_4 is H & V_5 is H	V is {H} or V is {(H, 0.8), (M, 0.2), (L, 0.0)}
4	1	V_1 is H & V_2 is M & V_3 is H & V_4 is H & V_5 is H	V is {H} or V is {(H, 0.8), (M, 0.2), (L, 0.0)}
...	...	...	...
243	1	V_1 is L & V_2 is L & V_3 is L & V_4 is L & V_5 is L	V is {L} or V is {(H, 0.0), (M, 0.0), (L, 1.0)}

Here, {H} is a high, {M} is a medium and {L} is a low degree of Environmentally Responsibility index. Table 3 presents two different approaches for producing the total index: ER is {H} with implicit uncertainty handling and ER is {(H, 1.0), (M, 0.0), (L, 0.0)} with explicit uncertainty handling (1). It has been decided to keep the weights to be one for all the rules, i.e. assigning the same importance to each rule. Examples of a belief rule taken from Table 3 are:

*R1: IF Energy performance improvement and monitoring is **High** and Energy performance improvement and monitoring is **High** and Energy aware networks engineering adherence is **High** and Social commitment is **High** and Waste management is **High***
THEN ER index is High;
*R2: IF Energy performance improvement and monitoring is **Low** and Energy performance improvement and monitoring is **High** and Energy aware networks engineering adherence is **Medium** and Social commitment is **Low** and Waste management is **Medium** THEN ER index is Medium,*
*R3: IF Energy performance improvement and monitoring is **Low** and Energy performance improvement and monitoring is **High** and Energy aware networks engineering adherence is **Low** and Social commitment is **Low** and Waste management is **Low***
THEN ER index is Low,

where belief degrees are attached to three referential values and weighted equal. Upon inference completion total ER index ($\sum_{i=1}^{N} V_n$) is generated with the following breakdown: Initial level for 0-20% range, Beginning 20-40%, Improving 40-60%, Succeeding 60-80% and Leading 80-100% accordingly. The total ER index is displayed without uncertainties in a single deterministic value in percentages, i.e. V is {H} or V is {M} or V is {L}. Additionally, output result shows the total ER index score and sub-category score breakdown in %.

RESEARCH RESULTS AND DISCUSSION

As a proof of concept, a Java web-application "Environmental Responsibility Toolkit for SMEs" has been developed, with JBoss Drools inference engine to provide the reasoning mechanism. The inference engine has been populated with rules described in Table 3, where an inference starts iteratively searching for the pattern-match of an input and if-then clause. If it is true, the relevant if-then clause is fired triggering an appropriate action. However, forward chaining of the JBoss Drools mechanism is not equipped with uncertainty handling. Therefore, in this research it is decided to deploy an evidential reasoning and forward chaining with a hybrid knowledge representation inference scheme to deal with imprecision, ambiguity and fuzzy types of uncertainties (Jian-Bo Yang, Dong-Ling Xu 2002).

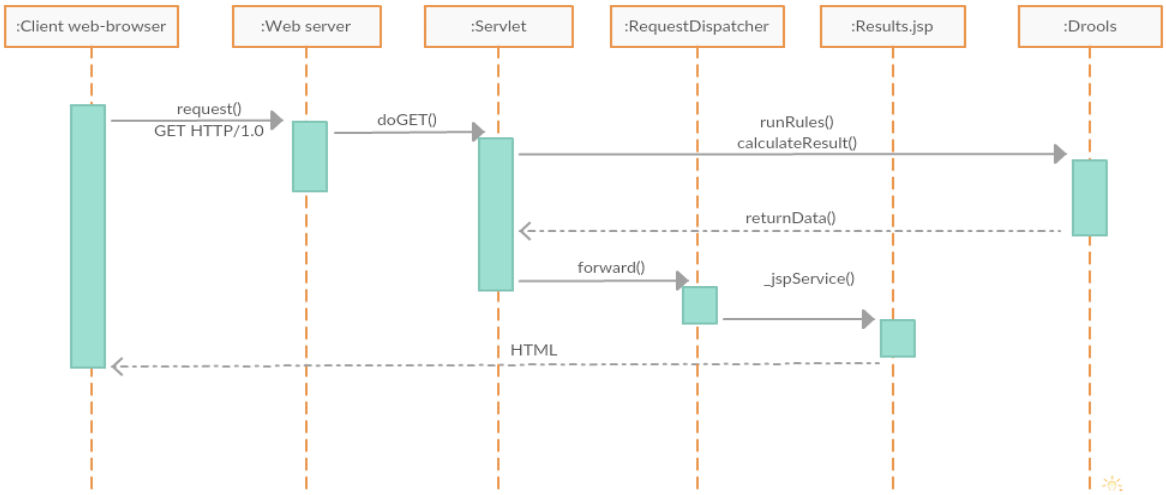

Figure 2 - ER assessment sequence diagram with BRB approach

The assessment itself encompasses a questionnaire with 17 items to be responded with predefined degrees of uncertainty for each rule defined in Table 3.

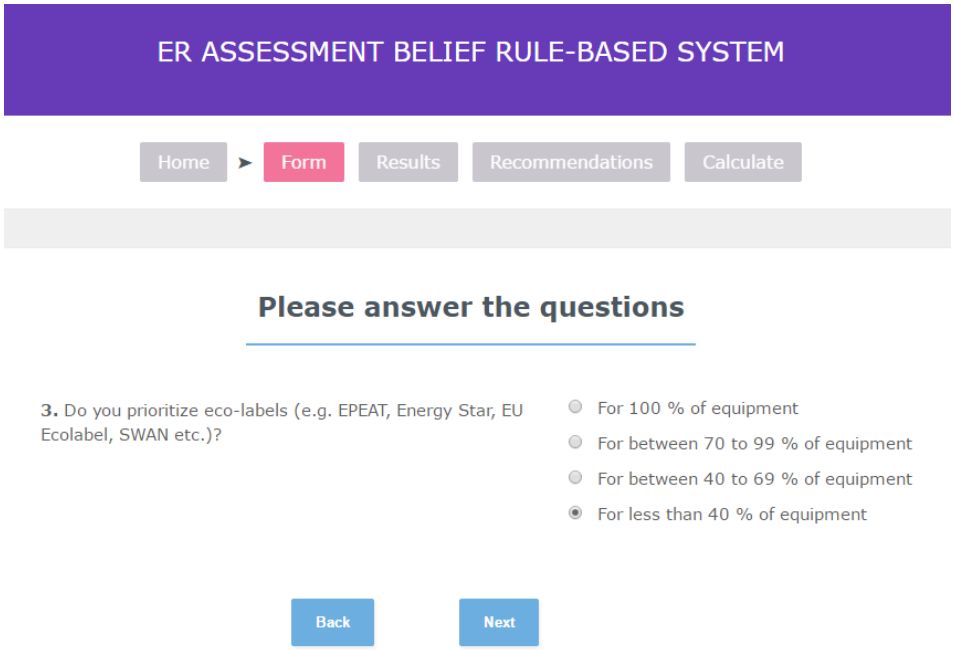

Figure 3 – Assessment questionnaire

Upon completion of the questionnaire, the Results is automatically analyzed and the page is displayed with a total ER index score and sub-category score breakdown.

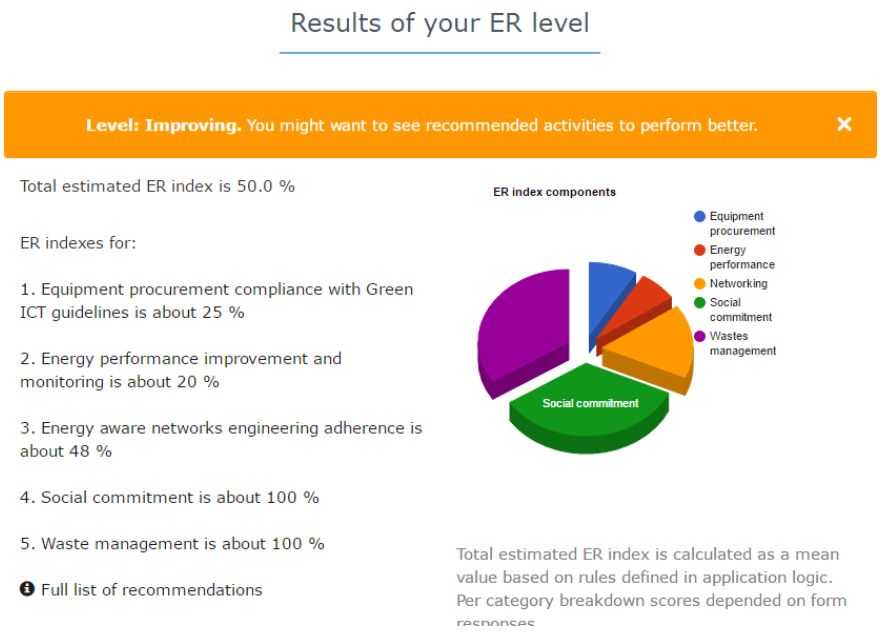

Figure 4 – Results of an assessment

Also, based on the results, an individualized set of recommendations to improve the Environmentally Responsibility level is presented. Recommendations that the respondent is assumed to fulfill completely have a corresponding “green tick”, when answered positively: Yes, Always, For all.

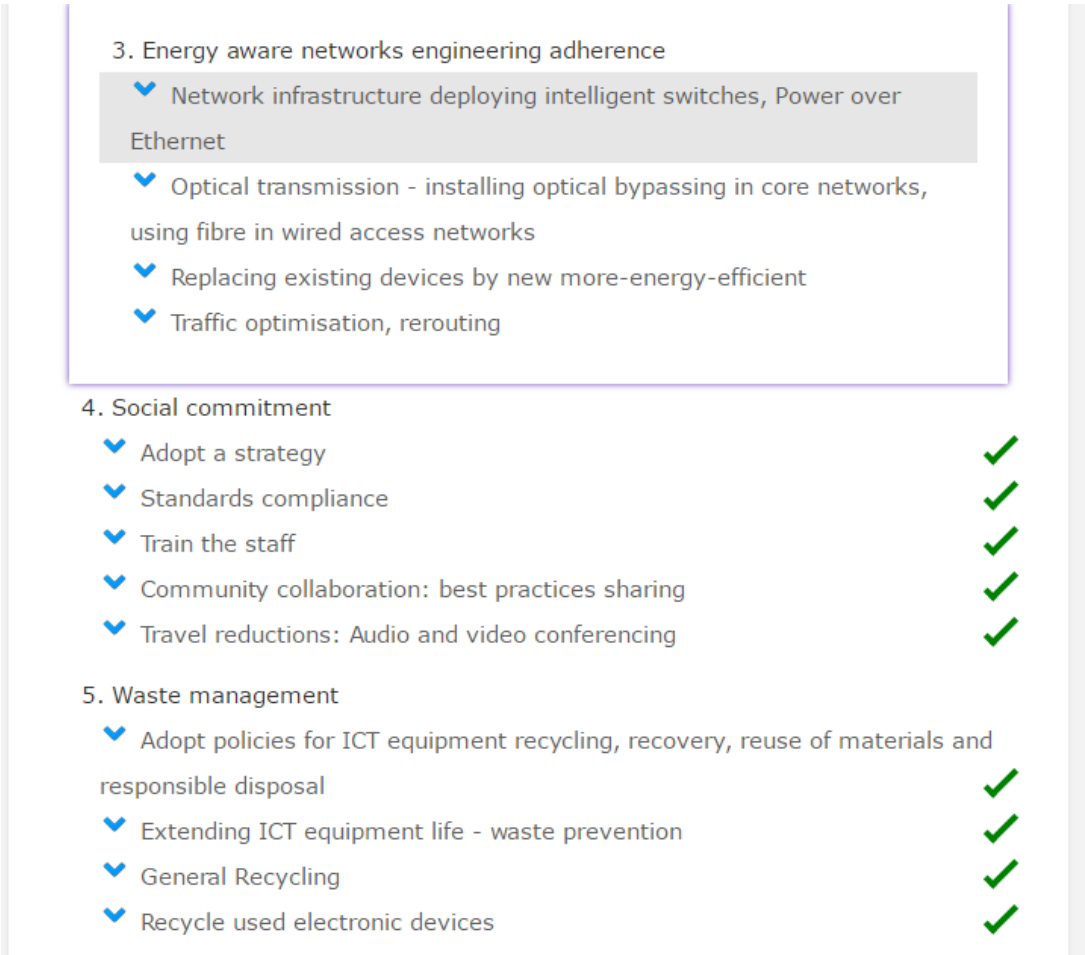

Figure 5 – Recommendations

Each of the recommendation activity is expandable on hovering on it, this is to provide more information on the activity along with references. Recommendations are based on "Best Environmental Management Practice in the Telecommunications and ICT Services Sector", EU Draft Background Report for the development of an EMAS Sectoral Reference Document, November 2015 (European Commission, Joint Research Center 2015).

For the purpose of ER BRB assessment validation, evaluation sessions have been held with experts, non-experts, and the target SME. Six domain experts were invited to perform formative and summative evaluations to address validity, reliability and accuracy of a system developed.

- Expert 1 is a British Library IT department employee, holds major in ICT for Environment;
- Expert 2 is Web Operations Manager/Technical Director;
- Expert 3 is a Professor at University of Hull and BCS Green IT Specialist Group member;
- Expert 4 is a Managing Director at sustainable IT consultancy company, BCS Green IT Specialist Group member;
- Experts 5 and 6 are author's supervisors: Senior Lecturer, Course Leader for MSc Sustainable Computing and Head of School of Computing, Creative Technologies and Engineering, Faculty of Arts, Environment and Technology at Leeds Beckett University.

Summing up the results, participants expressed positive opinions about the system, reviewed that the software has been developed in compliance with specifications, software systems development standards and best practices.
The target organization is a design and architecture medium-sized enterprise, specializing in the design of Residential, Office, Commercial, Assembly & Recreation projects. The case study has been conducted and the system has been found to be "*a good resource for those attempting to improve their corporate resources efficiency".* Company respondents' remarks on recommendations can be summarized as:

> *Recommended activities are diversified and only high-levels cost savings, with capital investments less than 1000 USD, will be considered for an adoption. Moreover, activities with a payback period of less than a year are considered to be more preferable for a target organization.*

Thus, low level cost savings delivering activities are less likely to be implemented by a target enterprise. However, it should be mentioned, that the potential of individual low-scale activities in contribution to combined large-scale environmental impact minimization is enormous.
Environmentally responsibility problems are represented with a large number of non-exhaustive factors. The literature review revealed inconsistency and diversity in existing assessment models which indicates the domain haven't reached itvi saturation point and is not conclusive. Clearly, further research is required in Green ICT readiness domain categorization dedicated to enterprises.
The originality of solution lies in the deployment of Belief Rule-Based approach in assessment of such a broad concept as Environmentally Responsibility. This paper shows that BRB methodology gives more leverage in inference procedures compared to traditional summative methods used in existing models analyzed in Literature Review. The research also shows that BRB technique could be applied in other problems with uncertain, ambiguous and fuzzy knowledge-based systems. By defining each possible combination of input attributes in rules and executing corresponding inference procedures the BRB system is believed to generate well balanced, sensible and context adapted results.
Another important implication of these findings is that the Recommendations part of BRB system will help enterprises to focus on making improvements on operating in a more sustainable way. One of the classical contradictions in sustainable development is e.g. when the particular best practice leads to energy efficiency improvement, but at the same time results on the production of electrical and electronic equipment waste (WEEE). The recommendations presented in the system do not accommodate these issues. Although, it is important for the participating company to analyze economic, environmental and social trade-offs. The balance can be achieved if the company follows the recommendation in the order they are presented, from procurement until equipment's end of life.

CONCLUSION

This research has attempted to determine an organization's Environmentally Responsibility level using a BRB approach with implicit uncertainty handling. There are many relevant methods for handling uncertain, vague and ambiguous problems. However, Belief Rule-Based approach has been chosen to be the most suitable in ER context. For example, Bayesian inference modeling requires complete knowledge about each parameter (belief degree) for the rule to be fired. Consequently, the process of an assessment could get more complicated, as it would involve more than one expert-respondents per assessment. That contradicts with the research aims of a project to be an easy to use and self-assessment toolkit for small and medium-sized enterprises representatives, who don't possess required human and time resources.
The BRB approach employed for ER assessment has been tested and validated by experts, non-experts, and the target SME. Future research is to test the usefulness of the assessment in practice and benchmark the results among a pool of similar type of enterprise respondents. It is believed that such a system generates well balanced, sensible and context adapted results. The aim of this Environmentally Responsibility Assessment System is to help small and medium-sized enterprises focus on making improvements on more sustainable business operations.

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EMERGENT COMMUNITY GOVERNANCE;

A model of socially sustainable transformation in New Wortley

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Keywords: Community Engagement, Live Projects, Interdisciplinary, Social Sustainability.

ABSTRACT

Following the 2009 Community Plan's (Graham et al, 2015) lack of impact in Leeds' most deprived area New Wortley, community leaders rethought their approach to achieving change. The Community Plan had been guided by a physical masterplan, a conventional approach that could not deliver the necessary social transformation. A new method subsequently developed, termed here as emergent community governance.

A bottom up process evolved through a ground swell of mutual action. Empowerment of a diverse collective formed a series of relationships informing a cohesive, fluid and inclusive community strategy, embedding a feeling of mutuality throughout the community stakeholders. The paper reflects on a transformation within this community as a result of shifting change processes.

Project Office, Leeds Beckett University's (LBU) 'design and research collaboration of staff and students' (Warren & Stott, 2014) is embedded in the collective, using skills across a range of disciplines to design the physical environment in tune with the community's strategy. Part of the refocusing is the construction of New Wortley Community Centre, a 7-year co-design live project completed May 2016.

As John Thackara (cited in Hyde, R. 2012) asserts 'Critic and environmentalist similarly calls for designers to evolve from being the individual authors of objects or buildings, to being the facilitators of change among large groups of people', thus this paper demonstrates how developing mutual relationships amongst the community and the so called 'professional team' can have a significant impact on the creation of socially and economically sustainable environments.

The evidence in support of this model is multifaceted; £759,497 BIG Lottery funding to construct the building, Our Place grants to support the new strategy through an Our Place plan, an NHS pilot scheme to create a Health & Wellbeing Centre with Project Office as co-design coordinator.

This paper demonstrates that there is a shift from masterplan led models to models such as emergent community governance as an appropriate means to deliver desired transformations in deprived communities.

INTRODUCTION

The New Wortley community has been on a remarkable journey since the completion of the New Wortley Community Plan in 2009. LBU's School of Architecture and Project Office have been working alongside them as a technical stakeholder from late 2009, supporting a marginalised but proud and vocal community.

The New Wortley Community Plan

In 2009 New Wortley residents, supported by Planning Aid (RTPI, n.d.a) and local stakeholders produced the New Wortley Community Plan. Despite not having statutory force, Community Plans (ODPM, 2004) are valuable because they enable the public to produce development plans for their neighbourhood. It is recognised that *masterplanning*, on its own, is not sufficient as a viable means of regeneration. The New Wortley Community Plan, therefore, tried to tackle issues of social isolation, drug misuse, health and wellbeing by prescribing a cocktail of community classes and services, better outreach, improved health facilities and new community support workers.

However, problems arose because Community Planning is associated with legislative planning, and necessitates the co-stewardship of a planning or design professional working alongside the community. This meant that with its focus on planning design, issues as important as 'social isolation' could not possibly be adequately captured. The problem with well-intentioned community master planning is that its professionals retain the upper hand resultant of their technical expertise.

Figure 1. LBU architecture students first site visit 2009

They lead the process and decisively are leading it well before the real issues and their solutions can be articulated and embedded by the community. The non-planning issues that were actually covered in the Community Plan played a subordinate role, appearing in the document as a wish list. The connection between the drawn masterplan information and the overall wider vision was disconnected. The plan also lacked a coherent implementation strategy.

New Wortley's Community Plan was initiated by the community as a tactical

opposition to the demolition proposals in Leeds City Council's (LCC) Leeds West Gateway Framework (Leeds City Council, 2010). Its triumph was to thwart an ill-considered top down imposition on their community. Maureen Ingham chair of New Wortley Residents' Action Group explained to the writers, '*without the Community Plan we would not have the community as it is today. The plan by Leeds City Council was to demolish the whole area including the four tower blocks and gentrify the area, meaning the replaced houses would have been beyond original residents' reach in price*.'

Beyond this successful activist act none of the planned spatial changes to the area were implemented. This was because of the lack of financial means to support its delivery, a lack of faith in the system and also recognition from community stakeholders that the masterplan was not as important for the transformation of the area as the non-spatial programme, which subsequently became the focus of their effort.

Leeds Beckett University's involvement

In 2009 LBU's School of Architecture began working with New Wortley Community Association (NWCA). The architectural brief was to design a new community centre next to the existing one, doubling its size. Curiously, this was not a project that was included in the Community Plan, yet the quantity of new services, classes and activities deemed necessary to help transform the area meant that a new building was essential to accommodate them.

Maureen Ingham explained, *'to deliver community facilities in the plan it was agreed with myself and Cllr Alison Lowe that LCC would fund a business development manager to turn the centre around and deliver the part of the plan relating to the community centre itself. Bill Graham was selected to fill the post and worked with myself initially on delivering and shaping the future of the centre.'*

Architecture lecturers Simon Warren and Craig Stott developed a close working relationship with NWCA and its users as initial design work by architecture students began. Big Lottery funding applications followed, co-written by Warren, Stott and NWCA. This participation helped the authors understand the journey the community had been on and how they were beginning to refocus.

The physical master plan was shelved with a new process evolving from the bottom-up. It was a ground swell of mutual action, starting with the community association, of a diverse collective who formed a series of relationships. From this, over time, emerged a cohesive, fluid and inclusive *community vision* and *strategy*. The community was beginning to *do it for themselves*. They recognised that to move forward, control over their issues had to be diverted from top down (although these could be well meaning) external providers to the community itself. This led the writers to think that something significant was beginning to happen.

The authors instigated the community centre design as both a practice-based and practice-led research *architectural live project,* including participation in community consultations, public meetings, board meetings and many unstructured conversations with individuals living in New Wortley as part of the co-design approach. In 2012 the theory of *emergent community governance* was posited and the research additionally became focused on this. This has led to a combination of ethnographic research and participatory action research being undertaken for this paper. It is noted that these methods naturally overlap because of our embedded role.

Maureen Ingham, chair of New Wortley Residents' Action Group in 2009 and currently a NWCA board member was interviewed to assist our understanding of continuity throughout the period of covered by this paper. Bill Graham, NWCA's Community Project Manager and similar Yorkshire and Humber Our Place project leaders answered questions by email, as a comparative research exercise to validate the concept of emergent community governance.

Localism Act 2011 and Our Place

Coinciding with the community's new direction, the Localism Act was introduced in 2011 (DCLG, 2011). It implemented a key objective of the Coalition Government to 'decentralise' decision-making and empower local communities. Four key measures are described:

- *new freedoms and flexibilities for local government*
- *new rights and powers for communities and individuals*
- *reform to make the planning system more democratic and more effective*
- *reform to ensure that decisions about housing are taken locally*

The two parts of the Localism Act of use to NWCA's work are:

1. Community Rights
The five Community Rights are, Community Right to Bid, Community Right to Build, Community Right to Challenge, Community Right to Reclaim Land and Neighbourhood Planning. Community Rights can be beneficial, for example, Community Right to Bid has been successfully demonstrated at Bramley Baths (Poulter, 2013).

Neighbourhood Planning is currently under consideration (see Graham's comments below) as a community masterplanning tool by NWCA. Considering the criticism of this methodology, it is now a wait to see whether it can be used successfully alongside their excellent Our Place work. However, the writers think that NWCA is correct to proceed to a spatial design method *only* after the development of community governance and its consequential *real change* impact.

2. Our Place
'*Our Place aims to give people more power over local services and budgets in their neighbourhoods'* (Locality, n.d.a). '*In December 2013, DCLG commissioned Locality*

and partners to deliver Our Place 2014/15 which currently supports 118 areas to develop an operational plan by March 2015' (Locality, n.d.b).

'Our Place puts communities at the heart of service delivery in their area and involves local partners within a neighbourhood coming together with local people to identify the issues that matter most to them' (My Community, n.d.a).

NWCA recognised that the Our Place programme was a better way to deliver change in comparison to planning led regeneration of their Community Plan. In September 2014 NWCA became part of the network of 118 areas to develop an operational plan.

The first output funded by Our Place was the New Wortley Conversations Report (Newton, 2015). Its purpose was to:

- *find out what local people think and feel about the community*
- *what could be done to improve the area*
- *to help build a partnership with service providers*

The report's approach is based upon the idea that people are *'experts in their own situation',* stating '*their knowledge and experience should be respected, and that they should be fully involved in decisions or developments that affect them. Primarily we consulted people 'on their own territory', i.e. by going to places we know they will be (on the street, cafes, community centres, events, etc.)'* (Newton, 2015). LBU students helped with public consultation events held at the existing community centre.

Figure 2. Summer BBQ at New Wortley Community Centre

The results described the positives, the major social issues facing the area and ideas for improvement. It led to the setting up of a successful network of local partners; the main contributors alongside NWCA were Barca Leeds, Leeds West GPs, Castleton Primary School, Leeds City Council, Rachel Reeves MP and the Police.

The Localism Act is working well at New Wortley but the writers' anxieties remain about the motives of the Government. Rt. Hon. Greg Clark MP, Minister of State for Decentralisation introduces the Localism Act stating, *'For too long, central government has hoarded and concentrated power. Trying to improve people's lives by imposing decisions, setting targets and demanding inspections from Whitehall simply doesn't work. It creates bureaucracy. It leaves no room for adaptation to reflect local circumstances or innovation to deliver services more effectively and at lower cost. And it leaves people feeling 'done to' and imposed upon - the very opposite of the sense of participation and involvement on which a healthy democracy thrives'* (DCLG, 2011b).

The words are credible but was the real motive the Conservative's ideological position to reduce the state? Local authorities through widespread *austerity* cuts have been radically scaled back. Or, was Localism more influenced by its Liberal Democrat co-authors and therefore more about genuine participation of society in its affairs? The Liberal Democrat Co-Chairs of the Parliamentary Policy Committee on Communities and Local Government advised, '*The Bill is now much improved from when it started, and will really change the way we do local government in this country, with new tools to increase participation, and give councils a greater ability to make the decisions that are right for their local area. It has greatly benefitted from having a strong Liberal Democrat influence throughout its passage through the House, and will be a better Act in practice than it would have been without our influence'* (Brooke, A. Lord Tope, 2011).

The writers believe that well resourced local authority governance has an essential part to play supporting communities to flourish and to safeguard the poor and vulnerable in our society. Erosion of local authorities under the guise of reducing debt, in a time of so-called austerity, will not adequately compensate disadvantaged communities by some positive outcomes of Localism. That is not to say that local authorities do not need to change, they have to make some big strides and devolve to and trust communities much more - less top down, more bottom up. As witnessed in the EU Referendum there has been a popular backlash to political orthodoxy across most of the UK. We think that emergent community governance has surfaced as a direct consequence of a condition of political neglect in disadvantaged communities prevalent over many years.

Emergent Community Governance

The authors believe there is a new generation of activist regeneration underway. The chosen expression for this is *emergent community governance*.

If Localism is seized by communities as a means of community activism, so it is not

just about having influence but about affecting governance then how far could social, environmental and economic transformation go?

This theory has developed through collaboration with New Wortley and its community association, having seen the community grow in its ambition, begin to flex its muscles, be listened to and become confident. Their legitimised voice has become a potent instrument for change and our provocation is that could lead to a more radical '*strong governance*' (My Community, n.d.b) contrary to that the authoring politicians of the Localism Act might have intended.

The Oxford Dictionaries definition of emergent is *'in the process of coming into being or becoming prominent'* (n.d.) and through its activism and reflection the community has discovered its method and realised its position. The belief is that *governance* simply came about through necessity, and once articulated, began to grow and be shaped.

This model is at an early stage, but is it ready to be called *governance*? Governance is defined here as *'the processes of interaction and decision-making among the actors involved in a collective problem that lead to the creation, reinforcement, or reproduction of social norms and institutions'* (Hufty, 2011). Certainly, there are '*actors*' - the community and its technical collaborators and there are *'processes of interaction and decision-making, involved in the collective problem'* - the transformational vision defined most eloquently in the New Wortley Conversations report and the New Wortley Our Place plan. The community's network of mutual action is operational and evolving, but it needs longer to reach maturity. Only then could it confidently be known as *governance* and be able to substantiate that it *'lead to the creation, reinforcement, or reproduction of social norms and institutions'*.

New Wortley's Emergent Community Governance in Context

It is important to compare the New Wortley experience with other Our Place projects to test whether *emergent community governance* is showing signs of life elsewhere. Within the Yorkshire and Humber region there are 15 projects that have been supported. Although Our Place has a clear methodology, there is no blue print, just a framework of objectives that steer participants towards a successful outcome.

Seven of the fifteen projects (which includes NWCA) have very similar objectives and means of achieving them. They identify health and wellbeing, employment, skills, environment and safety issues as common problems. Each has developed a mutual network of stakeholders that is charged with governance of the vision. Could they be exhibiting *emergent community governance* as have been defined at New Wortley? Key people at the seven comparable projects were sent the following two questions by email to help inform the theory. Three responses were received. The answers were edited to key points, and referenced as follows:

- LD. Linda Dellow, Chief Officer, Centre4, Grimsby.
- BG. Bill Graham, Community Project Manager, New Wortley Community Association, Leeds.

- TD. Tony Dylak, Chief Operating Officer, Royds Community Association, Bradford

Question 1. Can Localism (specifically Community Rights and Our Place) be used to deliver a new kind of governance, radically changing how decisions are made and by whom within communities? Or is Localism simply a pragmatic way for supporting community projects?

LD. *'Localism as a concept has merit but in practice little has changed in terms of what power is deferred and the methods of transfer tend to enable larger organisations to benefit rather than community groups. This kind of governance is unachievable at a time of rapid service transformation as people try to ensure their 'sustainability' in a rapidly changing voluntary and community sector (VCS) and public sector. Organisations with 'power' are risk averse in this environment and political pressures mean that anyone without a 'track record' gets little opportunity to take or receive power.' Dellow goes on to state that Centre4 is, 'using our local network and relationships with key individuals to get things done. We act more as innovators, influencers and honest brokers rather than power mongers / managers.'*

BG. *'Communities across the UK, in disadvantaged areas are notoriously difficult to engage with, there are a lot of reasons for that, but many of these communities will have been promised 'change' at some point and either been let down or it wasn't the change they were looking for. Again areas that are high in deprivation tend to have been for a long time. Doesn't really matter what political party or philosophy is in charge at the time, the impact on people's day-to-day lives is minimal. Localism gives us a chance to ensure local problems are dealt with locally.'*

TD. 'Party politics are proven to be untrustworthy. The new kind of governance takes party politics out. The new governance is by people not interested in party politics, for example – a local mum campaigning for a playground is a 'politician'. Local people know what the answers are. There are opportunities for local people to be political without being party political.'

Question 2. Is there a bigger vision emerging or at play in your area?

LD. *'Multiple ones, which is part of the problem. Devolution, Brexit, and other changes at regional, national and international level are all impacting on the vision for the area and how it can be achieved.'*

BG. *'Yes there is a bigger vision, the idea of a community led body taking more control of the environment and the housing locally – whether through transferring management of the estate and buildings to the community, and or looking at the association (NWCA) becoming the developer at the heart of the future plans for the area. We have looked at a neighbourhood plan (which would require the formal voted support of the local people) whereby we shape and control the future of the area, taking our own destiny onto our hands. Going forward the plan is getting the work we do to be recognised and commissioned, so we are not so reliant of grant*

funding. The association can be the means whereby local people can get involved, by volunteering, training or even working – as we have demonstrated. Money being brought into the area should have a direct result in terms of creating jobs and opportunities for local people – this in itself is a very direct way to lift people out of despair and give them hope.'

TD. '*Public bodies have lost the ability to adapt, the analogy is that they are oil tankers slow to change direction; we are a speed boat and can change direction really quickly. There are lay members in 1000+ organisations nationally doing things like us, allowing ordinary people getting into how their community works; it works best where local authorities are not involved, free of restrictions. Once people get it they never go back, it's the right way to work, we get more done.'*

As stated in Dellow's answers, some organisations will use Localism as a practical tool to carry out their projects. This is to be expected and a larger sample of respondents would be needed to explore this. Significantly both Graham and Dylak display an urgent tone caused by a persistent political condition that has led to the disenfranchisement of their communities. Their communities, on the whole, have developed a total distrust of party politics (both local and national). These two communities have responded out of necessity through the only option remaining - *self-governance*. Localism, at this moment, is a significant opportunity in the pursuit of self-governance, defined here as *emergent community governance* in the example of New Wortley. Both Graham and Dylak have stated that their communities are not restricted to Localism, it's just one method, it is important to consider any opportunity available.

Figure 3. New Wortley Community Association workers and volunteers

So far…..

The community network has brought in over £3 Million of investment to date, and now that the new community centre is open there is twice the space for the community to use. A Power to Change grant has secured modest capital to start the conversion of the existing community centre into a Health and Wellbeing centre, for which Project Office is the architect. These two facilities will host many of the services, groups and support initiatives raised in the New Wortley Conversation report and the Our Place plan around health, wellbeing, isolation, skills development and employment. Our Place funded posts, mostly taken up by local people, support these.

Figure 4. Landscape volunteers working outside the new community centre 2016

CONCLUSION

What next?
In conclusion there are two areas of further work and research of relevance to the writers.

1. Technical Stakeholder
PO will continue to be involved as a technical stakeholder embedded within the New Wortley network. One of the seven key ideas from the New Wortley Conversation Report is for *'Improvements to the environment'* and this will be PO's next major commission. LBU's landscape design students have developed an urban realm strategy, co-designed with the community which will lead onto detailed design work and implementation, subject to fundraising.

Design work has started on the reconfiguration of the existing community centre's entrance as it is transformed into the Health and Wellbeing Centre. A bike library for the repair and hire of bikes will be situated in a converted shipping container next to the community centre.

All of this work will form a physical urban strategy, six years after the masterplan of the 2009 Community Plan was abandoned. The conclusion is that, only now, after years of consultation, collaboration, capacity building and mutual network building all distilled into its governance model is the community's vision ready to be defined as a physical plan.

2. Research
Localism is the opportunity that some marginalised communities are using right now to confront issues of exclusion. We have articulated this moment as *emergent community governance*, a radical idea of communities taking control of their situation. Localism is just one tool, what are and will be the other ways that this takes hold? To track and evaluate this further, New Wortley and similar communities will continue to be the area of study.

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PROJECTS NEED TO ADD VALUE; NOT JUST SPEND MONEY

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Keywords: Business-case, Innovation, Management, Value.

ABSTRACT

This paper adopts the position that a 'value' concept should guide the development of projects. Any contemporary interpretation of 'value' cannot readily ignore the importance of the 'sustainability' concept to a notion of value that each project seeks to contribute to. The ISO 55000 for Asset Management (BSi 2014) for instance, places particular emphasis on a 'whole life cost' appreciation of value. An indicator of the value added by projects comes from the NAO audits of Public Sector Projects, showing that 34% (NAO 2016) were at significant risk of not delivering successfully. It may be that this is similarly the case in the commercial sector, presenting a broad view, and a negative one, of the sustainability of project outcomes. This research sought to report on issues arising in the development of a 'value case' for projects. It makes use of a case study consultancy undertaken by the Leeds Beckett University's MSc Strategic Project Management staff which was about assisting a project department that was responsible for managing the building assets of a hospital, and which provided the muse for the problematic issue of determining 'project value' or 'project success'. Additionally it considers the evidence of a focus group of mature part time MSc Strategic Project Management students, who as practicing project managers, had a range and depth of experience. It found potential indicators that developing reliable measures of 'value' and its associated measures of 'benefit' to develop reliable business cases for projects is a challenge for organisations and projects. It found that project managers and the departments that ran projects experienced a variety of processes and decision making which appeared to detract from the selection of projects that would deliver value outcomes. The paper proposes that further work is undertaken, using quantitative methods, to examine this issue by testing the hypothesis: "Project selection on the basis of value is compromised by the governance processes employed in selection".

INTRODUCTION LITERATURE

It may be that there is a prevalence of conditions in organisations that compromises the management of projects. Cooke-Davis (2002) pointed to a number of these but saw the 'correct' alignment of processes as being the solution to successful project development, and Morris (1997), Morris, Pinto, Soderlund, (2010), also pointed to this issue of the environment that projects exist in, seeing the 'management of projects' as not being a problem, (in general they concluded that people knew how to deliver projects), but that these were compromised by the pressures in the environment they arose in and served. Cooke-Davis (2002) saw the issue of 'project success'
(as opposed to 'project management success') as being resolved by the corporate body's setting of suitable measures that aligned project outcome with measurable parameters. The variability of project types, purpose and scale, mean that measurement of performance is in itself problematic. This problem of performance measurement allows for some doubt about the NAO (2016) and Cooke-Davis's (2002) methods whose assessment relied on qualitative methods to determine whether projects had succeeded or not.

Layered onto this issue in the organisational development of projects is the issue of 'business case' inaccuracy identified by Flyvbjerg (2014) and Gray (2009) both of whom separately showed that typical business cases in organisations included exaggerated benefits and under estimated costs and schedules, things which serve to present a more favourable 'business case'. Something termed a "*tactical exaggeration*" by Flyvbjerg (2014) and termed "*a conspiracy of optimism*" by Gray (2009). Gray's and Flyvbjerg's work showed that these 'enhanced' business cases were attempts to achieve the *authorisation* of the business case, authorisation from the Governance structure/mechanism, and not a realistic presentation of the actual situation upon which governing managers could make informed decisions. In general project business cases showed confirmation bias.

HM Treasury issued guidance for Government projects in their 'Green Book' publication "Appraisal and Evaluation in Central Government" and in it identified that project business cases should represent 'value for money' and offer sustainable outcomes. (HMT 2003). Other publications point to how value might be interpreted for projects development, Association for Project Management's (APM) Body of Knowledge (BoK) 5th Ed (2005) saw value as a ratio of stakeholder satisfaction divided by resources required to deliver this. But the APM's Value Management Special interest Group (APM VM SiG) challenge this calling into question the notion that 'value' can be arrived at through what might be interpreted as a compromise between various stakeholder interests. The APM 6th Ed (2012) relies on an interpretation of 'benefits', perhaps avoiding any value debate, and saw benefits being defined by the project's parent organisation. Morris and Jamieson (2004) also advocated the advantages they saw in delivering strategy through projects. The relationship between value and benefits might be seen as: value being a ratio of *benefits* divided by resources required to deliver them. Within the APM's 6th Ed BoK (2012) a link to 'benefits' can be found between the setting of organisational strategy and the determining of 'benefit measures', which appear as 'performance indicators'.

The NAO (2016) noted that: *The three key challenges for the Authority and departments during this Parliament are to:*

prevent departments making firm commitments on cost and timescales for delivery before their plans have been properly tested; .....

"..and put in place the systems and data which allow proper performance measurement."

develop an effective mechanism whereby all major projects are prioritised according to strategic importance and capability is deployed to priority areas; .....

Taking each of these points in order:

prevent departments making firm commitments on cost and timescales for delivery before their plans have been properly tested; .....

This appears to be a reference to the tendency noted by Flyvberg et al (2014) and Gray (2009) for business cases to be exaggerated. This 'conspiracy' as Flyvberg saw it, might also be a simpler '*planning fallacy'* issue. This is the term given by Kahneman and Tversky (1979) to explain a heuristic estimating bias that tended to lead to *under*-estimates of resource and time.

develop an effective mechanism whereby all major projects are prioritised according to strategic importance and capability is deployed to priority areas; .....

This comment refers back to a 'Portfolio and Programme' management mechanism, described in the APM's BoK 5th Ed.(2005) and with more complexity in the APM BoK 6th ed.(2012). Portfolio (the selection of projects by a method and their de-selection due to performance or demand changes), and Programme management (the coordination of those projects running together, that could potentially interact to create new synergistic value), where projects would be prioritised according to their value to the organisational strategy, and not by, for example, the budget. (Reiss 2007). Work by researching students on the MSc Strategic Project management course at Leeds Beckett, raises some doubt that programmes are readily able to capitalise on programme coordination opportunities in the way the theory envisioned it.

Thirdly the NAO (2016) report recommended:

"..and put in place the systems and data which allow proper performance measurement."

This could be a reference to the notion of 'benefits management' and 'benefits realisation' which might (according to the MSP's 'managing of successful programmes', method) happen post project delivery, as other members of the programme office would both measure whether project benefits had been delivered and also 'realised' that the organisational is now exploiting those new assets provided by the project.

Cooke-Davis (2002) proposed that corporate value that would be delivered by its projects should be measured by "*sustained long term value creation*". (Cooke-Davis 2002 pp189)
Value however is a complex concept, Pollack (2007) showed that the value concept might be part of the 'sense-making' that would happen as the team and consulted stakeholders considered the problem the project sought to address.

In summary, value is a concept that is not absolute, and can be influenced by stakeholders' perceptions, and interests. Project management as a profession (APM) has evolved to meet this challenge by identifying 'benefits' as a method to align projects and programmes to organisational

strategy, where 'organisational strategy' should be the link with benefits, that might be enhanced by developing a series of performance indicators that allow project business cases to be made that align with strategy and can be then readily measured. Cooke-Davis (2002), Morris and Jamieson (2004), Thiry and Deguire (2007), all saw strategy being better delivered through a project management approach. Morris *et al* (2010) however identified the problems in poor project outcomes as existing in the organisational environment not the project processes. In side stepping the holistic concept of value and effectively relying on a benefits concept, determined by a strategic planning process, the organisational processes for governance must then be robust enough to provide an oversight that would ensure 'value' is being proposed by each project and does not instead deliver isolated performance indicators at the expense of other risk factors. Factors such as cost and schedule overrun, or compromise on the benefit outcomes themselves.

This paper positions 'value' creation as central candidate to the issues that persist in the development and management of projects. A value concept exists in the context of the project's strategic environment and adds variability depending on: the strategy being pursued; the ability of the organisation to meet that strategy; the risks of the benefits delivered being translated from potential to actual organisational practice. The focus group reports of project managers in the findings section might illustrate how vulnerable projects are to delivering projects that offer no valuable outcome.

RESEARCH METHOD

This paper's findings report on an action research (consultancy) outcome into a case study of the challenges faced by an Asset Management section within a large publically funded organisation. Action research is an acknowledged research method and is typically applied to management consultancy type work. (Stringer 1996) , (Dick 2002). This approach might be termed realist, the research here relies on interpretation, as symptoms and remedies are coded by the researchers who interpret what is happening and how it might be interpretated. As it is with case study research (Yin 2009) the findings are limited to the case but allow for hypothesising that this might be an indication of a wider issue.

To provide some further indication, the paper supplements this with the outcome of a small focus group of part time MSc students who were all senior practicing project managers and had a depth of experience to call upon. At best this sample can only be seen as anecdotal and here it is used to provide a number of indicators that could be considered when undertaking a larger, more robust study. The sampling and questions posed at the focus group; mean that the inferences cannot be generalised to a wider population. However, Symon and Cassell (1998) show how for social science in particular, where inquiry was more difficult and variable than in hard science areas, the use of qualitative methods such as: *life histories*; the *use of stories* and also *critical incident technique,* can yield outcomes of worth to research. In this paper the focus group outcomes can be viewed as borrowing from these approaches, and the limitations are acknowledged.

Researchers from the MSc Strategic Project Management were asked to help prepare a proposal for an asset management department running building service projects. The organisation believed that asset maintenance projects were being proposed with the intent of capturing additional budget spending funds from a large capital investment project that was being run alongside normal operations and maintenance.

Anecdotal cases from a range of sectors in an MSc focus group were solicited in an afternoon focus group that looked at the way authorisation processes compromised project selection decisions and consequently meant poor value decisions were made.

FINDINGS

Designing a solution to the spend problem.

An asset management department responsible for the delivery of building service related projects and minor works, (Case 'A') was found to be developing cases that added function without regard to a wider concept of valuable. Researchers on the MSc Strategic Project Management course at Leeds Beckett University were asked to propose a solution. It was the assertion of one of the capital project managers that the 'raid' on the capital budget (as they saw them) was irrational as many projects that might have been undertaken for maintenance, missed opportunities to save energy, down time, and improve performance.

The researchers took a 'basket' of projects from the maintenance department and put them into a programme management tabula format. The intention was to look at how the selection of proposed projects and projects in delivery, might be compared with one another for a variety of business cases, most notably: *Compliance cases; Energy savings; Added functionality leading to increased output.*

Then some 'confidence' assessment was made to identify whether each project's case was risky in terms of the business case, (simple high, low, medium, categories were applied). Where forecasts were made (few did have objectively measurable forecasts), the 'return' was tested by halving the forecast of benefits and doubling the cost estimate. Some projects in the 'basket' survived this test, showing them to be realistically likely to deliver a valued outcome. A table of projects prioritised in terms of 'value' once a risk factor was applied was arrived at. This allowed for the projects to be compared with one another on the basis of value rather than 'spend amount', which is what had happened previously. Making whole life cost comparisons would have been the most technically accurate way to achieve this for these types of building service engineering projects, but in practice proved problematic given the interconnected nature of the systems and the absence of any data to allow this. This seems like a typical dilemma for organisations. To get around this problem the researchers instead simply identified whether there was a consensus amongst engineers as to whether each project would increase or decrease the operating cost to the organisation. This simple measure served to close the debates on the degree of value that might have been added and revealed that some projects would add value and some (most) would not. What remained clear was that some projects added significant value and others some certain value, and many did not add any value. Most projects did not present a business case that involved measurable outcomes making them unverifiable, and appeared to be not able to add value. Cases in this instance were made on spurious references to specification guidelines which, either: did not exist; or had been misinterpreted/misapplied or else were at the discretion of a senior authoriser or to meet a stakeholder's request.

To attempt to create some initial triangulation data, the MSc Strategic Project Management course at Leeds Beckett University, ran a focus group from among its mature students from the part time cohort. This cohort includes experienced project managers from a variety of sectors. The illustrations presented below, serve along with the Case 'A' findings, to provide an indication of the experiences

of organisational governance processes and decision making that provide some basis on which a hypothesis might be formed. They also serve to provide an indicator that the Case 'A' may not be untypical.

Notes from the project manager focus group. Sunk cost error.

The project manager inherited a project to model tool and machine behaviour by using a couple of simple tests; the potential savings in production were immense. On checking the plan a number of assumptions had been made regarding tests on machines that were impractical, the extra work required to complete the tests raised the project cost from £100k to £124K, this seemed a simple and easily justifiable change, given the likely benefits. But it was a cost the client refused to allow.
The extra work included a commercially viable design to test rotating spindles, something that had never been done previously.

A business case was made (quite strong in our opinion) by a strong team of academics and engineers and myself, to justify the additional cost, the client's response was that he was prepared to waste the initial figure of £100K but not the additional cost and asked how much to wind the project up, the client's reasoning was that the budget had been reached. Our cost to wind up was £115K which meant that for the cost of £9k the client could have had a full working model.

Award winning, poor investment.

Projects concentrated on the Water Quality improvement schemes in the early days of water privatisation by building some awarding winning new plants. These plants won their awards for architecture and existed in places that could not be seen by the public. The operational running costs went up. Which seemed like a poor investment a few years later. Although the company needed better treatment that did not need to come at increased prices. Other water companies did better and in the regulated market and the company began to reap the unwelcome impact of this approach to project investment.

Much later the contrast was made with plants that were disguised as attractive farms, for instance, were much cheaper on construction, and designed for running efficiency. After a years' long campaign had been waged by operations to get plants that were better to run.
In effect, many of the capital projects had reduced the company's operational efficiency, rather than improved it.

'Contractor' Pumps.

Pump manufacturers in the UK have a range of pumps they refer to as: "Contractor Pumps". These are significantly cheaper than other pumps in the ranges offered, perhaps a third cheaper. However they are more expensive to run, by a significant margin, on spares and maintenance and energy. They sell because the Contractor building the plant is engaged through cheapest price and so price in these products. In fact, manufacturers often sell these products at a loss, seeking to make the profit on subsequent spares demand.
Some operations departments, (this happened in the case cited here) replaced 'contractor pumps' as soon as possible, and often this meant significant housing alterations.

For E&M plant the capital purchase price rarely represents more than 8% of 'whole life cost'.

Head Office Approval of Larger Budget Projects.

In this organisation, many capital maintenance and plant improvements projects were continually being delivered. Almost all stayed under the 500,000 euro limit, beyond which the projects of 500,000 euros and over, needed to go up to Head Office for approval.
A casual glance at the project budget totals revealed this.
Most worrying was that projects that easily broached the 500k limit were split into phases, each phase coming under the budget authorisation limit.
This compromises organisational Governance.
It may happen because the higher approval takes so long, or is particularly onerous.

Benford's Law.

In an asset organisation a similar list of projects existed, the application of *Benford's Law of controversy*, a mathematical formula that tests for the randomness of numbers between 0 &10, (http://en.wikipedia.org/wiki/Benford's_law) showed that the numbers 4 and 9 occurred more often in the random group of numbers taken from the budget list of project totals. Indicating that this practice of limiting budgets to come under authorisation limits occurred elsewhere. ("499" perhaps illustrates why the more frequently than normal numbers are *both* '4' and '9')

Avoiding Burning Hours.

This refers to the practice of moving costs between projects, perhaps an obvious example is where a single project manager or contract manager moves (or books costs to one project from another) costs between project budgets he or she is controlling.
This is motivated by wanting to make all projects/contracts look as if they are performing satisfactory, when in reality one might be making a healthy margin and one overspending.
The true performance picture is obscured, as one project/contract subsidises another.
The implications for this are:

- That project cost performance is not accurate.
- That some contracts make more money than is reasonable. (this affects future bidding)
- That some contracts lose money, but we do not acknowledge this. (this affects future bidding)
- That audit detail on costs is lost.
- That *good* clients (those who make the project easier for the contractor) subsidise more difficult clients, or riskier contracts from other clients, perhaps even their competitors.

Close a failing project.

In managing an IT reporting tool, which included a 'quick win' phase, a faster but simpler solution, which the team would deliver first and run for just 6 months while the main system was developed. After a while it became clear the most the 'quick win' would realise was 3 months reporting, and that this might be an optimistic hope.
The idea of a 'quick win' is useful, but it was not working here.
The project manager reported the situation and advised that the 'quick win' was abandoned and the team concentrate on the main project.

My Programme Manager said: *"There was no way we would be 'seen' to fail at a project and that we were to go ahead anyway".* To save face it might be assumed. The project manager told the team to abandon the 'quick win', and that they ought not to mention it. No one noticed because benefits were not tracked.

Hospital Bin Store.

A project to build a secure hospital bin store reportedly cost of circa £90K. (It was called a "*Secure medical waste facility*")
Taking into account the [some of the] end users requirements, and request, a designer was commissioned to design to the latest hospital design guidelines and BS EN standards a secure bin store.

The design and costs was approved by default because the approval governance allow projects to go through if the costs were within 10% of the PTE, (*Pre-tender cost estimate*) and therefore the project got the go-ahead from the capital investment board and an order was placed. The bin store had automatic doors, the latest technology in terms of lighting and very securely built, all to match the brief.

Unfortunately the space allocated to build the store was on a slight gradient and therefore proved difficult for end users to use once the bins were fully laden.
The store remains unused. (Casting doubt over the need for it).
It would seem that the job was designed to match the budget not the requirements.

DISCUSSION

The small sample size of projects reviewed in Case 'A' did not allow any firm conclusions to be drawn, but it did raise an inference that, within the case organisation many projects added no value, but did have a tendency to increase other costs, such as energy use, and maintenance or (in one case) license fees. Where compliance projects (to upgrade facilities to modern systems) were presented in the 'basket' of projects for Case 'A', these invariably involved an increase in operating costs, yet typically in Mechanical and Electrical plant replacement: energy; maintenance; and down-time improvements, could be realistically expected.
The Case 'A' organisation was under some pressure at the time to reduce its running costs, which makes the presence of a programme of projects that seemed to avoid contributing to that outcome, (when this was an area that could have made significant gains), seem to indicate that a structural problem might be influencing this.

Whilst no conclusions can be drawn from the purely anecdotal stories from the project managers' focus group, they may be an indicator that the design of organisational governance processes and the availability of oversight in authorisation processes, means that many organisations focus on *spend* authorisation rather adding value. Perhaps enough to make the issue worthy for further examination. Gray (2009) and Flyvbjerg (2014) showed how project business cases tended to suffer exaggeration, and how that misrepresentation served other purposes. Cooke-Davis (2002), HMT (2003), APM (2012), NAO (2016), all make clear the importance of governance processes and benefits measurement, to support the better selection of projects. The findings of this paper indicate that the need to spend money, the need to meet component performance indicators, and the structural design of the process of strategic planning and its budget setting, served to set up pressures that may be leading to projects being focussed on *spending* the budget money available rather than creating

a valuable return for the investment. Sutherland (2007) showed how vulnerable rational decision making was in human systems, when other pressures to conform are present.

Of particular interest is the apparent dismissal of the sustainability policy intentions that each case organisation nominally promoted.

CONCLUSIONS AND LIMITATIONS

All the focus group illustration case organisations and the Asset management department managing building assets, possessed sustainability policies, or some sort of stated commitment to sustainability. This did not seem to robustly apply in the selection and development of projects. It may mean that there is a variability of application of value added intent from individual project managers and teams, but there appears to be the capacity for failure in governance authorisation processes and oversight in the organisations considered here. Some subjectivity is inevitable as 'value' is a subjective concept and attempts to make the measurable performance indicators 'objective' sees a reduction of most 'value concepts' to include faceted aspects of an otherwise open system concept, and for some organisations externally set regulatory measures. While 'value' concepts are open to interpretation, the findings showed that many projects fail to meet even any broad interpretation, and consequently are someway distant from presenting more truly sustainable outcomes. It might be inferred that improving the observed situations in this study, and the development of project proposals, might in itself allow for an important step towards better sustainable outcomes. The *errors* that allowed these examples in the findings to become actual projects that failed to meet a 'valuable' outcome seem to be mostly attributable to a budget orientated process pressures, either to *not spend*, or perhaps surprisingly, more frequently; *to spend* the budget available, regardless of the opportunity cost or negative impact that might have on running costs and subsequent resource requirement. Were the indications in this study found to be true in a wider piece of research, they would support Morris's (1997) suspicions that projects suffer (not from issues to do with the technical know-how around building them), but from the organisational environment they find themselves in; one that leads to poor selection. The implications of this research show that the holistic concept of sustainability might not permeate down the organisation and that unsustainable investment decisions are normal and could be prevalent. Were this to prove the case in a more wider ranging quantitative study, it would be a consideration for those interested in sustainability. 'Sustainability projects' (those installing green technologies) are not necessarily immune from faulty investment decisions. The popularity of anaerobic digestion technology over accelerated composting might be an indicator of this. Green technologies need to also be set within the economic and social contexts they operate in.Were organisations cited by the focus group and case study work described in this paper, to examine their approaches to the development, the governance and the selection of projects, the resulting improved investments would have a positive effect on sustainability.

A hypothesis may be developed from limited indicators in this study. The study allows for the construction of a more robust quantitative study to test the hypothesis, that: *"Project selection on the basis of value is compromised by the governance processes employed in selection."*

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THE PROGRAMME MANAGEMENT 'FLOW' PROBLEM

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ABSTRACT

Sustainability studies have a tendency to focus on technology. Less attention is devoted to processes by which sustainable value is developed in strategic planning processes that lead to project proposals. 'Programme management' theory is focussed on the better coordination of projects based on a benefit or value perspective which can be associated with improved sustainability.

'Programme management' theory seeks advantages that can be created by better coordination of projects in a programme and by placing an emphasis on each project's relative 'value' contribution. This research illustrates the challenges faced in implementing the theory of 'programme management' in practice; it utilises a qualitative in-depth set of interviews to examine four large programmes of projects. Literature largely concurs on the themes and facets of the theory of 'programme management' and little attention is given to the experience of managing programmes in practice, although the NAO (2016) showed that 34% of projects offer no beneficial outcomes.

The cases in this study showed 'programme management' theory could contribute to better project outcomes, but some programme structures prevent it. In the study's cases, four main issues were shown to be important for 'programme management', these were: Dealing with the structuring of the complexity of programmes with 100+ projects, to achieve meaningful visibility for analysis and review; Arriving at objective criteria for the measurement of benefit; Identifying a value based approach to setting project priorities across the programme; Ensuring that there is a sufficient flow of viable and value adding projects from feasibility to firm proposal.

The findings indicate that the sustainability of many projects may be compromised by the process environment of the programme they are in. It infers that significant improvements can be achieved in creating more sustainable value. Consequently being aware of those negative drivers should improve the development of more sustainable projects.

INTRODUCTION

This research reviews five cases of organisations that asked Leeds Beckett University researchers for assistance in reviewing their approach to managing programmes of projects. The research sought to identify factors that were likely to improve the effectiveness of projects in a 'programme'.

Although often presented as an established process, the concept of 'programme management' that is promoted by the Organisation of Government Commerce (OGC) and professional body sponsored courses in the U.K. (APM 2005). 'Programme management' is developed further into a more complex deterministic format in the Association for Project Management's (APM) Body of Knowledge (APM 2012), as a recommended way of delivering strategy. This approach to strategy delivery through 'programme management' is proposed by the Department for Business Innovation and Skills (BIS) (2010) guidelines and by Project Management writers such as Murray-Webster and Thiry (2000) and Sowden (2007). However in practice programme management approaches are more variable. The application of 'programme management' then can be observed to be varied and without consistency. Given the variance in organisational sector challenges this might be expected, and rather than a defined 'management process' 'programme management' might be better described as a theory.

Arising out of an APM Special Interest Group (APM 2016), the original intention of 'programme management' appeared to be to achieve the greater coordination of projects across a portfolio of projects that were, or could be connected in someway. This connection might simply be that they call on similar resources, for instance within a single organisation. Programme Management might be seen as the formalised codification of a way of managing complex groups of projects that might have been occuring in the normal course of management. The APM's Body of Knowledge (2005) showed how they perceived programmes' relationships with 'portfolio' describing the portfolio as the totality of the work the organisation planned to do and that 'programme management' was a more deliberate intention to coordinate those projects, and other work, selected to be undertaken.

More simply, a 'programme' is generally described as a collection of projects that are grouped together, because they have some affiliation, perhaps they are all focussed on contributions to one organisation's strategy for instance. Once gathered together, at least in theory, other efficiencies could then be looked for. These efficiencies might for example include, using one contractor to deliver two closely related projects, perhaps generating a procurement overhead saving, and ensuring coordination of the works between the two, were that necessary (Reiss 2004).

The ability to better coordinate across projects in a programme offered the promise of synergistic benefit. Lycett, Rassau, Danson, (2004); Maylor, Brady, Cooke-Davies, and Hodgson (2006) saw it as a development that would dominate organisations' approaches to projects, partly because of the ability it offered to allow the promise of a greater degree of control over the delivery of strategy. Of particular note is the attention given in 'programme management' to that of 'benefits' and 'benefits management'. Control over strategic delivery can be noted as the second underlying feature of the theory of 'programme management', which itself might be a natural development from synergistic coordination based on a focus on 'benefits management' APM (2005); APM (2012); Lycett, Rassau and Danson, (2004); Maylor, Brady, Cooke-Davies, and Hodgson (2006).

The 'benefit' and benefits management concept to this research and to programme management theory is important. Seeing the projects in the programme as deliverers of what will ultimately become 'benefits' changes the way they might be perceived. Reiss (2004), for instance, posits that projects deliver 'products' but these 'products' offer only 'potential' to the organisation, only when the business/organisation exploits that potential does the 'benefit' become realised. Reiss perhaps demonstrates the disconnect that projects had, experienced with the beneficial intent that initiated them. Tied up with the APM's VM SiG's concept of Value,(APM 2016), 'benefits' are seen as a function of value where *benefits* divided by *cost* shows a ratio of 'value'. Here value becomes part of a value concept. Concepts of value are associated with sustainability and are implicit in guidelines from HM Treasury (2014) when talking about value for money and by the BSI (2014), but no explicit connection is made with sustainability. This might be because sustainability can be a quite testing as it becomes more highly defined and many investment projects while offering economic sustainability might not be able to lay claim to a holistic definition. Nevertheless, more sustainable projects are more valuable ones. Audits by the National Audit Office (NAO 2016) showed that perhaps as much 34% of major public projects where predicted to yield no measurable benefits (or value). It might be assumed that this is also the case for commercial projects and projects in general. Selecting and managing projects for the value they are anticipated to yield might be seen as a more sustainable way. More recently the ISO 55000:2014 For Asset Management (Jenkins 2014) describes a process of monitoring and maintaining and renewing assets that might be likened to Programme Management. This approach saw Programme Management as a way to manage complexity through coordinated groups of projects.

Lycett, Rassau and Danson (2004) listed the potential functionality and advantage arising from establishing Programme Management. Once projects were brought together in a programme, it was believed that both greater efficiency and greater effectiveness could be sought, reveiwing the literature available then Lycett, Rassau and Danson (2004) identified the following potential benefits:

Intially associated with better coordination, Lycett *et al.* (2004) noted that writers on this topic thought that greater efficiency could be achieved by; Improved coordination (assisting in identifying and defining project dependencies, thereby reducing the incidence of delay, rework and backlog); also improved dependency management (assisting the reduction of rework and improved interface) the more effective use of resources (assisting in prioritisation of resources and sharing efficient uses); the more effective knowledge transfer (facilitating the sharing of knowledge across projects in the programme, to identify and mitigate risks as they become known in practice); and greater visibility, (such coordination would rely on the ability for a coherent visibility of that list of projects).

Additionally Lycett *et al*. (2004) thought that greater effectiveness in the wider organsiational/business could be achieved by: Better communication, (facilitating governance and management control); and the better definition of projects, (Assisting 'portfolio' selection in terms of the selection and prioritsation of less risky projects, and the selection of projects by 'value' related concepts such as 'benefits'. 'Benefits Management' become a central feature of interpretations of the theory of 'programme management'. The 'benefits management' concept closely associated with 'programme management' allows for the definition and selection of projects, and their prioritisation, based on the value or benefit they offer to the strategy of the organisation. The consequences for this connection of benefits and coordination idea is that 'programme management' could be associated with the alignment of strategy, and so 'value'(Reiss 2004; Lycett *et al*. 2004; APM

2005; APM 2012; APM 2016b) thereby potentially creating more sustainable outcomes for the projects undertaken.

There is little if any debate about the definition of 'programme management'. Where writers on the topic differ is to add further conceptual potential and complexity. None have yet emerged to challenge the concept as it developed.

'Programme management' then is a construct designed with a mind to the better management of projects across an organisation, using coordinaton, and providing a focus on 'benefits' as outcomes. This focus on 'benefits' offers better coordination of strategy delivery, making it a potentially a strategic delivery tool. More successful strategies might be expected to exploit greater value from the project investments they make, and so be more likely to offer greater sustainability. 'Programme management' is a complex undertaking though, and is applied widely to many differing sectors. As such the approach lacks consistency in application across organisations.

RESEARCH REVIEW AND METHODOLOGY

This research opportunistically took a small collection of University action research projects all of which involved some aspect of the 'programme management' approach, and sought to identify the challenges that arise in the practice of managing programmes of project work.

Action research is an acknowledged research method and is typically applied to management consultancy type work (Stringer 1996; Dick 2002). This approach might be termed realist, the research here relies on interpretation, as symptoms and remedies are coded by the researchers who interpret what is happening and how it might be interpreted. Work with some of the cases described here continues and should changes be made might lead to this research becoming action research. At the time of writing the early stages of an approach has emerged from masters level seminar work with programme and project practitioners studying part time, and through more detailed research/consultancy reviews of other active programmes where University researchers have been asked to examine 5 specific organisational approaches. Data collection so far has been in-depth interviews and sampling has occured opportuntistically, a Leeds Beckett University's Masters course provided access to all the respondents. It should be noted that all the respondents included programme and project managers who are key employees operating and shaping the programme approaches. (These included: 2 asset management organisations; 2 manufacturing; and one public service programme).

RESEARCH METHOD

In each case the primary stated reason for asking for University researcher comment/advice was noted. (Table 1.) These are identified as the primary stated symptom. These requests for specific, external, objective advice on programme refinement each had primary symptoms that highlight the underlying challenge of implementating the theory of 'programme management' in practice.

These challenges were then compared in seminars with a mix of managers concerned with the running of the programme and University researchers and mature part time (and practicing project managers) masters students and alumni. The results of these discussions and reference to the theory of 'programme management' tenets, where used to help identify suitable and practically applicable

recommendations. The continued involvement of the actual manager/practictioners allowed for the detail of the case organisation to be considered and for the recommendations to be immediately tested for viability in the organisation.
What is problematic for the study is that the variability of the cases does not allow for comparisons to be accurately made. Meaning that the findings may not be readily applicable to a general population, though perhaps some inference that these recommendations might have several applications in practice in other orgainsations with similar challenges. The convenience sampling meant that only MSc students intiated the reserarchers' involvement and this in itself might introduce a sampling bias. This not withstanding, the outcomes were valued for local impact by the practitioners involved. Some were able to be further tested in practice by detailed application.

Four main symptoms leading to requests for assistance were noted:

1. Dealing with the structuring of the complexity of programmes with 100+ projects in them, to achieve meaningful *visibility* for analysis and review;
2. Arriving at meaningful *objective criteria* for the measurement of *benefit*;
3. Identifying a value based approach to setting project *priorities* across the programme;
4. Ensuring that there is a sufficient *flow* of viable and value adding projects from feasibility to firm proposal; (and it is this last one that might be of particular interest to the better development of sustainable projects).

Data on the requirements of the organisation, their strategic intent and challenges within the organisation were gathered using focus groups and interviews with senior managers and staff delivering or receiving [users] the benefits of the projects in the programme. This relied on a degree of interpretation by the researchers.

A common systematic method of data collection was not readily achieved given the nature of the source data, and researchers instead preferred to see the depth and richness of the issues. In each case the perceived worth of the recommedations (shown in table 1) could be reviewed with an involved manager (or more than this) from the programme concerned.

A more systematic approach can now be designed for future research based on this work.

RESEARCH RESULTS

The data gathered has been organised into a summary table in 'table 1'and 'table 2'

Table 1. Organisational Cases: Status of their programme management approach and The Issue Prompting Consultation with the University, the Primary Stated Symptom.

	Type of programme/ organisation:	Case 1: An Asset Programme Co.	Case 2: A Transport Authority Asset Programme Co.	Case 3: A Process Manufacturing Co.	Case 4: An Assembly Manufacturer	Case 5: An Infrastructure Authority
	Status of Programme at investigation:	Seasoned operator	Programme and Project Support Office in development	Developed and established programme of proposed work. Third year of the programme's operation	Collection of loosely connected contracts for a few clients	Programme and Project Support Office in development
	Issue prompting consultation with University (Primary stated symptom):	The flow of viable projects was not moving through the process, as much time was spent proposing/testing projects that failed to achieve a valuable definition. Efforts to improve the flow, led to the viability bar being lowered and unit costs of delivering benefits increased.	Dealing with the structuring of the complexity of programmes with 100+ projects in them, to achieve meaningful *visibility* for analysis and review. And also an anticipation that a move to a benefits based proactive approach would require a change in organisational culture.	Need to address an acute awareness that the projects identified in the programme will not all be undertaken unless greater throughput is achieved.	Bottleneck in design department and corresponding significant overspend on one large contract.	Need to establish a Project Support Office, Assumption that the components of a PSO will support the problem of the capital investment budget not being spent

Table 2. Organisational Cases: Issues as they were translated by the Researchers

	Type of programme/ ⇨organisation:	Case 1: An Asset Programme Co.	Case 2: A Transport Authority Asset Programme Co.	Case 3: A Process Manufacturing Co.	Case 4: An Assembly Manufacturer	Case 5: An Infrastructure Authority
	Issues Arising in the Effective Application of the 'Programme Management' theory ⇩					
1	Dealing with the structuring of the complexity of programmes with 100+ projects in them, to achieve meaningful *visibility* for analysis and review;	Managed by geographical breakdown.	Uncertainty about how to arrive at benefits management without adding in overwhelming complexity. Concern for programme in this very large programme becoming too large and unwieldy.	Unusually this was not a problem here, as a presentation format had been arrived at.	Bottleneck arose because of complexity in design. Assumed to be 'how it was'.	Not readily visible.
2	Arriving at meaningful objective criteria for the measurement of *benefit*	These were clear and set by regulator.	Progress had been made on developing the objective criteria but doubts about how these might impact on the programme and work culture.	Governance on the businesss case return is rigouressly applied.	n/a	Working to funder provided targets.
3	Identifying a value based approach to setting project *priorities* across the programme;	Compromised to meet investment flow demands. Measures to drive flow also made projects less valuable.	Priority setting had been reactive previously and there was concern	Priorities are set using a value based criteria.	n/a	Unable to meet the ROI predicted to solicit the funder's budgets.
4	Ensuring sufficient *flow* of viable and value adding projects from feasibility to firm proposal;	This was the initially percieved problem.	Although not at this stage, the indications were that identifying projects of *worth*, might prove difficult, once the initial repair backlog had been dealt with.	Priority ensures that the 'most' valuable projects are prioritised and least valuable projects are 'shelved'	Compromised by process bottlenecks.	Compromsied by difficulties in finding projects of value, and bottlenecks (insufficient availability) in the supply chain.

RESEARCH RESULTS

Case 1 was a mature programme based organisation, its approach to Programme Management had evolved through a series of restructures. At the time of involvement with the University, the company had identified a problem of too slow a flow of projects into the programme to be able to meet its spend targets. This case organisation had undertaken a number of surveys, consultative workshops and interviews, and arrived at a number of potential proposals. What seemed to be evident from this was the programme process had become siloed with unresolved project design issues being forwarded along with the unresolved element, to the next section in the process, ending up with a partnered contract supplier.

Solutions offered by the participants to the workshops involved attempts to 'pull' greater flow through the process. This would not possible, because the difficulty was in identifying projects actually worth doing, ones that represented value.

Further analysis conducted by the University compared sub-programmes which bucked the trend and added the projected value with savings, with ones that did not.

This revealed that more collaborative work with the supply needed to be undertaken to more readily identify projects worth doing, ones that represented value for money. It led the researchers to suggest that some 'stock' of project proposals were developed to remove the bottleneck and to do this in collaboration with the suppliers, to allow items like rates in the contract to be reconsidered. Early stage design work was too detached from the delivery process to allow for meaningful projects to be proposed with suficient regularity.

The rigour applied to project approval was lowered in order to improve the flow of projects and meet the spend targets. Here the difficulties in the project value identification process, led to a compromise on project selection being made.

In case 2 the organisation was seeking to move to a more proactive maintenance approach employing 'programme management', and had made progress towards identifying objective measures for benefits. Their primary concern at the time, was the complexity that was likely to arise from their very large asset base, one that covered a wide metropolitan area. They also were concerned that this represented a significant cutural shift away from what was a highly embedded work culture.

Complexity could be readily dealt with by applying a Workbreakdown structure that would see 'programme management' applied at depot level, here the organisation was reduced to much smaller manageable areas. The researchers described how, when objective measures of benefits were applied at the local area level, varying performance between areas could be usefully compared so each area provided benchmarks of performance for the others. In this way outstanding performance would be noticed and used to transfer good practice learning between areas. It was thought this would help with embedding the new culture, as the ability to compare performance and learn from it, should create a 'social conformity' (Sutherland 2007) driver.

Case 3, already had a visible programme, set out in a complex spreadsheet that could be filtered and sorted to view the programme in a variety of ways. Their stated problem was that the large list of identified projects could not hope to be delivered in the time available. To an extent they lacked design resource in the same way that Case 1 did. They were also able to readily identify the required value (ROI) of their projects and like Case 1 this placed their project proposals in a challenging constraint.

A prioritisation critieria based on the value of the projects was considered, and while not all projects in the programme could be readily prioritised, four from a hundred could be. These four projects represented at least 80% of the value in the programme. To realise this, and now understanding that the projects were worth developing, a Value Management and Engineering workshop was undertaken, engaging a wide representation from across the company. This yielded a significant value outcome on just one of the four projects.

Case 4's programme also suffered a flow of work problem, and in this case the bottleneck was identified, the design department. Once identified, the researchers were able to show the value of standardised design blocks to the operation, a solution that had been considered beforehand but rejected as not being worth it.

Case 5, sought to address its severe work flow and lack of completion problems by developing a Programme and Project Management Office (PPMO). Their issue was similar to Case 1's because they were finding it difficult to design and develop projects that would benefit themeasure cases they had raised their funding on. This left them with funds, but not solutions that could meet the required outcomes.

To address their issues it would seem that a number of components would be necessary: The development of objective criteria to make outcomes easily measurable; visibility of the programme; development of supplier capacity to meet the undertakings. The development of a PPMO could solve these, and would need to be cognisant of the causes of their issues.

DISCUSSION

The delivery of projects in programmes both deals with aspects of the issue of managing the complexity of projects (Murray-Webster and Thiry 2000) and also highlights a persisting challenge of the complexity of managing projects across a programme in order to achieve the advantageous coordination.

The cases show that the theory of 'programme management' might assist in the development of projects that add more value and potentially contribute to the avoidance of failure of projects to deliver any value. (NAO 2016). Of these facets of the theory of 'programme management' key aspects were: The objective criteria for measuring benefits that represented the organisational strategy; an ability to visualise the programme to allow comparisons and conduct coordination; a structure and organisation that removed the complexity to allow teams to follow what was happening; a commitment and understanding of benefits in the delivery teams and those overseeing the governance and selection of projects for the programme.

However, in the 5 cases reviewed by the researchers, other considerations not raised by the previous literature on the subject of programme management were identified. First among these was the need to be cognisant of the flow of work through programmes, and a holistic perspective. Both Gardiner (2005) and Hamilton (2001) discuss projects from a 'systems' perspective. In Case 1 the linear processes were so long that few in the organisation were able to develop a view of what was happening, their extensive surveying of work team members indicated this. Once identified, sub-optimal piecemeal solutions might have made the situation (in respect of value) worse, and flow was forced. Case 5, Case 3 and Case 1 indicate that for flow of work to be maintained, more than sufficient 'potential' projects need to be queuing up, the programme needs to be served as a sort of 'programme of problems', so a reservoir of areas for improvement can be called upon. These findings suggested to the researchers

that a reasonable 'reservoir' would be 2 for every one that was needed. It would also seem that insufficient emphasis has been hitherto placed on the need for a visual programme. In these cases the inability to list projects and filter those lists to allow teams to review the relative position of their project and of all projects prevented any coordination, prioritisation and review necessary for the management of a programme to a fuller potential and the realisation of the benefits described by Lycett et al (2004). Case 3 showed the potential of prioritisation to allow effort to be focussed in the most valuable areas.

CONCLUSIONS

If the cases reviewed here are representative of the wider use of 'programme management's' application, then it may be that the 'theory of programme management' while highly developed theoretically, does not reach this projected potential in some areas of practice.

Benefit realisation and selection of projects by value, was shown in the cases to rely on the careful choice of objective measures of benefit. Crucially the alignment of strategy offered by the theory of programme management's 'benefit management' concept raises the *projects,* undertaken by the organisation, to the position of being major components of strategy implementation, this was shown to be important in Case 3, and these points are supported by the literature. Lycett, *et al.* (2004); Maylor, Brady, Cooke-Davies and Hodgson (2006).

Little attention is given in 'programme management' literature to the *process flow* of projects through the programme. This would appear to be an area of concern for some organisations, and in the cases researched showed this to be an early indicator of inefficiency and compromise on value.

Creating a structured approach to allow programme visualisation was also shown by the case organsiations to be highly facilitative of prioritisation of programme review, but was not paid much attention in the literature.

What seemed clear from the cases shown was that a benefit focussed development of projects that employed a process similar to Value Management and Value Engineering would potentailly realise greater project value, and so contribute to sustainability (at least within this context of sustainability). The gap between possible and actual value added was significant in case 3 and indicates it to be worthy of pursuit. Cases 1, 2 and 5 appeared to have programme processes that prevented value engineering approaches and at least one of the cases appeared to have a culture that reinforced this. Case 1 actually had a workforce culture of promoting valuable outcomes but then a process that arrested it, much frustration in the work teams was evident.

Achieving sufficient innovation to deliver greater sustainable benefit in project definition proposals eludes some projects, and projects that offer no benefit are commonplace in the cases here and identified by NAO (2016). Teams instead are steered by programme processes towards a (perceived) less risky solution that mimics the tried and tested method/approach, and helps meet programme drivers, most notably spend/budget targets. Furthermore the organisational process need will encourage the selection and development of projects that add *no* value, or at least miss other opportunities for value adding project design. Value adding project strategies that might have then gone on to better contribute to organisational strategy as well as some or all aspects of the sustainability concept. The organisational process environment in which projects are proposed, selected and developed can have an important influence, either negatively or positively, on the

sustainability of the project outcomes. The cases considered in this study, supports the literature showing that some organisational programme environments are compromised, and that this might represent a common issue. This appears to be an organisational problem that has consequences for sustainable strategies and sustainable outcomes and one that can negatively affect the intent to deliver more sustainability. This might also occur even in 'sustainability' projects. It allows, for instance, even unsuitable 'green' technologies to be employed merely to spend an available budget rather than to better contribute to a wider sustainable goal.

Rethinking the approach to project selection and development may help deliver greater value from project work and create more sustainable outcomes in general.

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Sustainable Practice

THE INTEGRATION OF DESIGN, PROCUREMENT, AND CONSTRUCTION RELATIVE TO HEALTH AND SAFETY (H&S)

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ABSTRACT

Statutory requirements are prescriptive relative to H&S and its application within the South African construction sector. The role of construction H&S practitioners has increased substantially with the introduction of the Construction Regulations, statutory registration with the South African Council for the Project and Construction Management Professions (SACPCMP), and a defined scope of practice. The revisions to the Construction Regulations further increased the H&S responsibilities of clients and designers as the multi-stakeholders responsible for construction projects. Procurement practices are prescribed by the South African National Treasury, and are required to be applied and adhered to on all public projects, including the construction sector. Multi-stakeholders are required to ensure that construction projects conform to all statutory requirements, as well as procurement standards. However, despite the statutory changes there remains high levels of project risk, and an insignificant reduction in injury, occupational disease, and fatalities.

Action research conducted among multi-stakeholders in the built environment investigated the degree of integration of design, procurement, and construction, relative to H&S. The research sought to identify the levels of competency and confidence among construction stakeholders regarding H&S, and the ability to apply procurement processes, the design and construction aspects, as well as the statutory requirements applicable across the six stages of construction. Salient findings indicate the lack of integrating H&S along with all of the parameters included in the construction life cycle, and low levels of confidence among built environment stakeholders regarding H&S to design, procurement, and construction practices. The lack of integration of all factors result in statutory non-compliance and increased project risk. Further conclusions indicate resourcing and providing for H&S is lacking relative to projects from National Treasury, clients, and multi-stakeholders.

Recommendations include the inclusion of construction H&S in tertiary education, training, and continuing professional development (CPD), as well as further defining multi-stakeholder roles across the construction life cycle.

INTRODUCTION

The issue of construction H&S has been a longstanding challenge for centuries. It appears that there are multitudes of publications written worldwide, with discussion regarding the extent of accidents, disease, and fatality and injury rates in the construction industry. The sector remains one of the most hazardous and notorious industries across the globe, irrespective of the much-debated causes, and issues relative to injuries, disease, and fatalities. Yet despite changes to legislation, research, and increased focus in developing and developed countries, to date, there has been no significant reduction in such losses in the construction industry (Windapo and Oladapo, 2012; Construction Industry Development Board (cidb), 2015).

H&S research and knowledge relative to integrating design, procurement, and construction in South Africa does not exist, and even less so in the context of the construction life cycle. The role of procurement and how it affects H&S does not appear to have been previously considered, or researched in South Africa. The risks relative to construction are a joint responsibility of all stakeholders involved in the process and this research considers factors and outcomes that link design, procurement and construction relative to H&S. Workers are the downstream recipients of the industry, and are therefore directly affected by decisions relative to design, procurement, and construction. Furthermore, promoting workers' health and wellbeing advances the sustainability agenda, particularly given that the South African Green Building Council of South Africa (GBCSA) (2014) Green Star SA Socio-Economic Category Pilot of 2014 includes seven categories, No. 6 being 'Safety & Health'(S&H). There is a total of 13 points available, one point being relative to S&H.

The aforementioned amplify the need to investigate the relationships between design, procurement, and construction, relative to H&S. The paper is important, of current interest, and provides the background and explains the approach relative to previous work in the field. The needs relating to expediting better practice H&S in terms of the integral life cycle approach, the construction sector's sustainability, supply chain management (SCM), and the built environment, in terms of the building and civil engineering construction environments.

LITERATURE REVIEW

Introduction

Historically, H&S has been the contractor's problem. However, the European Council Directive of 25 June 1992 on the implementation of minimum safety and health requirements at temporary or mobile construction sites (92 / 57 / EEC) introduced the concept of client and designer responsibility for construction H&S. This spawned the 1994 Construction (Design and Management) (CDM) Regulations in the United Kingdom. The amended 2015 CDM Regulations place responsibility on the client, principal designer, and principal contractor. The client is responsible for setting up the project such that the H&S risks are controlled throughout the project. The principal designer manages H&S in the pre-construction phase, which is extended to the construction phase in terms of liaising with the principal contractor, the latter being responsible for H&S therein. With respect to South Africa, the client has duties which can be delegated to a construction H&S agent. Designers also have responsibilities, in addition to the principal contractor and contractors. In essence clients and designers are responsible throughout all six stages of projects, whereas contractors are only responsible from tender stage, through construction, ending at 'close out'.

In terms of the integration of design, procurement, and construction, the construction of the Olympic Park in east London is noted as a pinnacle of H&S success. Clear leadership and careful planning and implementation by the client and integration of H&S in all stages of the project are cited as some of the success factors of the project (Smallwood, 2015).

The benefits of Health and Safety in the construction life cycle

International literature indicates that clients have greater influence over project standards where there is involvement in H&S on their part from project inception. Where leadership and collaboration is seen in relation to H&S, benefits are more likely to be perceived and achieved, thus resulting in risk reduction during design, planning, and procurement (CIB W099, 2013). Despite multi-stakeholder responsibilities being entrenched in South African legislation, there appears to be a lack of commitment to the inclusion of H&S in projects (cidb, 2009; Windapo, 2013; Goldswain, 2014). Gambatese (2013) notes that the earlier H&S is introduced into the life cycle the greater the influence on project risk reduction. Furthermore, project liability is reduced when H&S is considered relative to design and complexity.

Regulating construction Health and Safety

The poor performance of the construction sector as a whole suggests a poor culture of H&S compliance among all construction stakeholders. Any person or organisation that employs people or works in South Africa is required to comply with the Occupational Health and Safety Act (OHSA), No. 85 of 1993 (Republic of South Africa (RSA), 1993). The Construction Regulations (CRs) were enacted through the Department of Labour (DoL) to safeguard lives and to improve product and process quality (cidb, 2009; Windapo, 2013). The CRs were originally promulgated in 2003, and amended in 2014. The amendments increased the requirements for the level of competence and accountability among stakeholders, more specifically, clients and designers (RSA, 2014). A further significant legislative revision was the implementation of a construction work permit (CWP) system, managed as a client requirement. Prior to 2014, notification to the DoL was required, but was a contractor function (RSA, 2014). Other critical changes that were implemented was the need to appoint competent H&S persons to either the design team or the contractor.

The CRs (Republic of South Africa, 2014) further introduced the dramatic requirement for those practicing construction H&S in South Africa to be registered with a statutory council. The change to the term 'competent' is notable, and is a theme that flows throughout the CRs (2014). The term refers to a competent person who has the necessary qualifications and experience, but also knowledge of H&S. The changes clearly affect all stakeholders. However, the level of resistance by clients and designers regarding their revised roles, involvement and responsibilities continues to be met with scepticism for H&S (Smallwood and Haupt, 2008; cidb, 2009; RSA, 2014; Deacon, 2016).

There are three levels of construction H&S practitioners who practice in the sector, that have been clearly defined by the South African Council for the Construction and Project Management Professions (SACPCMP) (SACPCMP, 2013a; SACPCMP, 2013b; SACPCMP, 2013c). The SACPCMP is one of the six built environment professionals (BEP) Statutory Councils appointed by the Minister of Public Works, and registers the construction H&S categories, among other. The construction H&S Agent (CHSA), or client agent, practices across all six stages noted in Table 1, and represents the client. The other 2 categories, the construction H&S Manager (CHSM) and construction H&S Officer (CHSO) practice across stages 4 to 6, and are generally employed by contractors.

H&S responsibilities among the BEPs have been noted as limited in South Africa. The limited knowledge relative to H&S has been identified in many undergraduate and post graduate education programmes. Minimal, if any, embedded H&S content and training is included in such training that is available to students (Smallwood and Haupt, 2008; cidb, 2009; Smallwood, 2013).

A study regarding the performance of CHSOs indicated that a number of significant barriers exist in their ability to ensure adequate H&S levels and resources on a project. A number of these include, exclusion from decision making, managing the site, lack of knowledge, and lack of authority. A further barrier included employment practices relative to CHSOs which are generally part-time or on a contractual basis (Smallwood, 2013).

Built Environment Professionals

Those practicing as BEPs within the South African built environment, are required to register with a statutory body relevant to the practices of the discipline. While not all BEPs are necessarily regarded as 'Professionals', a number of categories are. There are six statutory councils that register BEPs, which register architects; construction managers (CMs); construction project managers (CPMs); engineers; quantity surveyors (QSs); landscape architects, and property valuers. The BEPs can take on multiple roles and, if they have the requisite knowledge, work as key stakeholders within contracts, directly or indirectly as the client, designer, or contractor. Each of the six Built Environment Professional Councils (BEPCs) has noted the need to develop the scope of work, or what is known as the 'Identity of Work' (IDoW) (Deacon, 2016).

Table 1 indicates the percentage of the six BEPs, which record H&S interventions relative to each stage as contained in their respective IDoW.

Table 1, Construction Project Stages.

Project Stage	BEP involvement (%)
Stage 1: Project Initiation and Briefing	
Stage 2: Concept and Feasibility	7
Stage 3: Design and Development	0
Stage 4: Tender Documentation and Procurement	0
Stage 5: Construction Documentation and Management	0
Stage 6: Project Close-out	0

Health and Safety and Stakeholder involvement

Pivotal to any project, the use of competent stakeholders is imperative, and has major influence on the successful completion of a project. Stakeholders include the client, designers (across the built environment), and contractors (RSA), 2014).

Currently, contract documentation makes minimal, if any, reference to H&S, other than a cursory note that requires statutory compliance (cidb, 2009; Wells and Hawkins, 2010). The construction process is made more complicated by industry driven activities. Prescriptive legislation, industry standards such as supply chain management (SCM), procurement practices and related requirements are typical examples. In South Africa, the procurement practices and requirements in

the public sector are set by the Department of Public Works (DPW), with particular financial controls applicable at national, provincial, and district level. The National Treasury is the overarching organ of state, each of the provincial departments and other public entities controlled by the DPW are required to provide and maintain infrastructure (cidb, 2010).

Procurement and Health and Safety

Procurement within the construction sector relates to a project, which needs to be delivered on time, within budget and quality requirements that meet the expectations of the client. Further requirements include the meeting of organisational goals and strives to improve the efficacy of procurement activities (Plantinga, Voordijk and Dorée, 2014; Alharthi *et al.* 2014; Watermeyer, 2012).

The public sector is responsible for infrastructure development and delivery. The Infrastructure Delivery Management System (IDMS) in South Africa is a model describing the processes that make up public sector infrastructure management, used in various ways to implement projects (cidb, 2012).

There is a paucity of literature relative to the links, roles and responsibility relating to procurement and H&S, which includes South Africa. The use of procurement as an instrument to promote improved H&S practices has received minimal attention, and where guidelines exist, there is limited attention to improving H&S standards through the procurement route (Wells and Hawkins, 2010).

The client is increasingly being held responsible for H&S on projects, with shared responsibility among all stakeholders. Therefore, the terms of procurement need to ensure that H&S is taken seriously, and the client's interests are safeguarded. H&S problems encountered during construction stage could be avoided if due consideration were invested during the early stages of design (The Office of Government Commerce (OGC), 2007; Wells and Hawkins, 2010; RSA, 2014). The OGC (2007) states that H&S is integral to the project process, not confined to the construction stage, but considered throughout the project life cycle. Government departments need to do more than the minimum set by statutory H&S requirements. Wells and Hawkins (2010) state that many contracts make vague and general reference to H&S. However, without clear benchmarks and definitions of the terms used, such as 'reasonable precautions', such terms have a tendency to be ignored. Pricing for the project through the bills of quantities (BoQs) and 'making adequate provision for H&S needs to be assessed during the adjudication process (Wells and Hawkins, 2010; RSA, 2014).

Designing for Health and Safety

The CR (2014) changes have resulted in increased competence and accountability among stakeholders regarding H&S. However, research conducted among South African contractors indicates that the level of compliance on a project is directly related to perceived cost savings, and not the degree of risk (Windapo, 2013).

The most notable designing for H&S approaches appear in the United Kingdom (UK), the United States of America (USA), and Australia, where literature indicates that, if applied, at the appropriate time, has a positive impact on the outcome on the project, such as the London Olympic Park (Schulte *et al*. 2008; Gambatese, 2013; Smallwood, 2015).

RESEARCH

Research aim and objectives

The aim of the research was to identify the extent of integration of design, procurement, and construction relative to H&S. Objectives included to determine: the procurement practices at provincial and district levels of a public department; the levels of H&S competence and confidence among construction stakeholders regarding H&S, and the ability to apply procurement processes, the design and construction aspects, as well as the statutory requirements applicable across the six stages of construction.

Research method

The research method included action research (AR) using focus groups (FGs) among construction stakeholders to determine the procurement practices at provincial and district levels of a public department involved with building and civil engineering projects in the Eastern Cape, South Africa. The FGs for the research were originally identified to be held at two levels, to limit cost. The FGs were organised to include multi-disciplinary stakeholders to determine current practices, perceptions, and aspects as they related to the diversity of stakeholders and effects on the industry. Although descriptive surveys were also conducted, and therefore the study was triangular in nature, only the qualitative aspects and related aspects of the secondary data are recorded in this paper.

ATLAS.ti, a computer software programme that analyses qualitative data, was used to analyse the transcriptions for the research. 'Computer Aided Qualitative Data Analysis Software (CAQDAS)' is one of the forms of computer aided programmes used to analyse such data (Friese, 2014). ATLAS.ti was used as a tool for supporting the process of analysing qualitative data. The narratives were analysed and coded as three documents, or one Hermeneutic Unit (HU)) or project. Codes were generated from the statements and code co-occurrence (frequency of occurrence) function within ATLAS.ti. The analysis of the narratives identified a number of issues. A level of confidence (LoC) generated from the statements and code co-occurrence function within ATLAS.ti. Multiple codes were applied against the number of times or 'density' that the code occurred in the narratives. The actual codes were then grouped into 'families' such as 'stakeholders, and 'designers' to assist with the analysis of the data.

Three FGs were held, with a total of 31 participants that included the primary researcher, and the client co-ordinator who attended each FG. The first FG was held at district level, with the BEPs consisting of an architect, quantity surveyor, building inspector and a number of construction H&S practitioners from the client and contractors. The second and third groups were held at provincial level. Participants included a mainly civil engineering group of BEPs, consisting of professional engineers, contractors, a quantity surveyor, and construction H&S practitioners from industry and the client. It was notable that while those who were involved with the procurement processes were invited, none attended any of the FGs.

Originally, 11 questions were planned for each FG, as time was limited to two hours per group. The questions were developed in a semi-structured way to allow for interactive discussion and debate. However, due to time constraints, the questions were reduced to eight (8). While the FG questions were broad, the participants tended to 'collapse' the discussions, and the contents were actually quite similar in content throughout the 3 groups. Analysis of the data revealed three broad themes: (1) Stakeholder competence in H&S; (2) Procurement practices, linking H&S to the 6 Stages, and (3) Procurement, H&S and the Construction Work Permit.

Research results

Theme 1: Stakeholder competence in H&S

Theme 1 evolved from an extensive, in depth discussion regarding procurement practices at provincial and district levels that were required to comply with the requirements of the IDMS and National Treasury. The process commenced when the department was notified of the project, with either a 'Form B4' for the building group, and the Road Asset Management System (RAMS) for the civil group, to completion and hand over of the completed asset.

The participants were requested to indicate their understanding of the stages of construction relative to the procurement processes (expanded on in Theme 2), and then to indicate their level of competence across the stages.

Knowledge areas varied widely in terms of the experience in the field and the level of confidence (LoC) across the six stages of construction, opinions, and understanding of H&S. Understanding roles and the IDoW were included to some extent in the narratives. Short excerpts of the discussion points are included, in South African vernacular.

A client (Pr. Engineer) at provincial level, in the civil section acknowledged the lack of knowledge, but that H&S information was available and obtainable. Site knowledge and risk identification were indicated as lacking regarding H&S:

(Excerpt) ... *Yes, I know enough to know I don't know, and that there are a lot of areas that I need to get construction H&S involved, but hopefully I know where to, in what points I need to get them involved, and what I need from the….,* and *…To be honest, I don't think that I know enough to actually say that I would confidently pick it up.*

A client (Pr. Architect) at district level in the building section indicated a very strong opinion about H&S, that appears to lean towards the perception of seeing H&S as 'interfering' with the role of the designer. The participant further appears not to understand the role of the three construction H&S disciplines, or sees H&S as 'one', irrespective of the disciplines and scope of practice:

(Excerpt) *… I don't see the need for an H&S officer being involved till even stage 3 because what's the input going to be? You know we all know what materials are flammable blah blah blah blah…. what input is the officer going to have in the design stage? …. Many architects I know - I am not defending them, don't even think about that. People die, fall off scaffolding and blah blah blah. Ok, well, that's one of those things, if you have to build, you have to build it. But when you do design, things are of such a nature you have to think how you have to put things together. But I dunno. I still don't think we need the H&S officer.*

The construction H&S categories indicated in general that they were confident, and had a high LoC, but do not get appointed at the appropriate times. The participants mostly indicated confidence to work and advise at all stages of construction, which is a pre-requisite for professional registration with the SACPCMP, and the related IDoW. The issue of late appointments was repeatedly raised across all three groups, and the H&S categories relating their frustration at the 'loss' of opportunity to reduce risk on the project.

Theme 2: Procurement practices, linking H&S to the 6 Stages

In terms of Theme 2, the code co-occurrences indicated the stages and the construction H&S roles deemed to be involved. The co-occurrences correlated with the roles of construction H&S across the six stages of construction. In most cases the H&S participants noted that they are only appointed during stages 3, 4, and even stage 5. Stage 6 is not included as there was no discussion regarding construction H&S involvement. While that aspect or the broader components of it are known, a range of 'grey' areas exist as to where one part of a stage starts or finishes. The participants note that the inclusion of construction H&S at stage 1, 'Initiation and Briefing' is highly unlikely, as the information in the form of notification of which projects are going to be done is what is received. However, it was suggested that the appointment of the CHSA could be made during the latter half of stage 1, to prepare documentation required for inclusion in the tender.

All of the appointments and requirements noted during the process are legal minimums and do not constitute better practice, or link with international practices. The CHSMs and CHSOs indicate their involvement mainly during stage 5, but a number have indicated they had had experience during the tender preparation during stage 4, as well as issues with pricing of the BoQ.

In summary, there is H&S involvement in a 'fragmented' manner, or varying degrees of compliance. The 'gaps' in the procurement of construction H&S for legislative compliance places the client at risk should there be any accidents or fatalities that on investigation could be linked to the lack of inclusion during design. The information which is provided to the province or districts clearly have no information regarding risk from National Treasury.

Theme 3: Procurement, H&S and the Construction Work Permit

Theme 3 considered the notion of the links between SCM and procurement, H&S, and complying with statutory requirements. The FGs were completed in June 2015, just less than 2 months prior to the exemption period given for the industry to prepare for the implementation of significant changes to the statutory requirements. It was noted in the narrative (apparent in all the FGs), the department, at provincial and district level, was not ready to comply with the permit, and construction H&S persons as per the requirements of the CRs (2014). The client stakeholders noted the realisation of the pending lack of legal compliance as a serious concern.

The H&S participants' responses indicated they could assist with the submission of appropriate documentation, and the processes that could reduce the risk and potential project costs and delays. The lack of knowledge regarding the statutory permit requirements from SCM and procurement requirements was noted as currently increasing the risk to the client and the project, leading to increased project costs and potential delays. The need for policies, procedures and guides for all stakeholders clearly impacts on further support or actions relative to H&S from the SCM and procurement aspect. The effect of the lack of the information is the late appointment of the H&S stakeholders, that as indicated in the previous themes increases project risk.

CONCLUSIONS

Literature indicates that competency is lacking among all disciplines in the construction sector relative to H&S, and a range of barriers are present across the built environment, in terms of practice. SCM and procurement occur in a 'silo', with the focus on complying with the IDMS requirements, and largely excluding H&S. However, it was noted that the SCM and National Treasury requirements are all met. The critical findings support the notion of the lack of competency and LoC, regarding H&S and / or the six stages among the BEPs.

The LoC indicated related to the participants' own areas of work, but not across the disciplines. The BEP participants indicate a high LoC in their own disciplines, but not in terms of H&S. All of the BEPs indicated no formal training in H&S at undergraduate or post graduate level. Similarly, construction H&S practitioners, indicated a relatively high LoC in H&S, but not across all of the six stages as they apply to the projects. The lack of LoC translates into increased project risk. The BEPs who are responsible for ensuring and who in many cases represent the client, and application of the IDMS cannot fulfil all obligations if they are not recognised. Similarly, the construction H&S categories cannot influence design or any critical H&S issues if not involved at the appropriate stages.

H&S involvement could, therefore, be described as occurring in a 'fragmented' manner, which results in varying degrees of statutory compliance. Coupled with the lack of competence relating to H&S and hazard identification, the lack of appropriate or late procurement of construction H&S practitioners, places projects and stakeholders at risk. The result is inadequate and inappropriate levels of H&S on projects during the life cycle, linking the lack of H&S to the high levels of fatalities, injuries, and diseases.

RECOMMENDATIONS

Recommendations include the need for H&S to be included in undergraduate and graduate education within the tertiary education sector for BEPs. Further research regarding the role of the integration of the SCM and National Treasury and H&S is needed within the sector. Promotion with clients and National Treasury is required to ensure consideration with H&S statutes. The dissemination of research findings and workshops among voluntary associations (VAs) within the built environment as CPD could assist with increasing knowledge in H&S, and the understanding of the roles that the construction H&S categories perform on a project. The application of the recommendations will further assure a level of sustainability within the sector.

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"TO ENCOURAGE PEOPLE TO THINK" – THE POWER OF BUILDING CONTROL INSPECTORS IN SUSTAINABLE CONSTRUCTION

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Keywords: building control, building regulations, social influence.

ABSTRACT

In England, national building regulations govern aspects of a building's environmental performance. Compliance with the regulations is assessed by Building Control Inspectors who review designs and inspect on-site construction. However, little research has been carried out previously to investigate the role of these professionals in sustainable construction. Semi-structured interviews were conducted with 20 building inspectors and four key informants from relevant professional bodies in England. Half of the building inspectors were based in private firms and half in local authorities. The building inspectors tended to position their power as wholly derived from the regulations. However, this stood in contrast to their descriptions of day-to-day activities and objectives which included providing advice and guidance, effective membership of design teams and a collaborative relationship with contractors/builders, architects and members of the public. Application of French and Raven's (1959; Raven 1992) typology of power demonstrates that, in fact, other bases of power are available to, and are used by, building inspectors. Beyond the 'reward' and 'coercive' bases intrinsic to certification and regulation, and the 'formal legitimate' power of their legislative role, the building inspectors also deploy 'expert' and 'informational' power. The primary conclusion is that, with greater recognition of the varied bases of influence available to them, building inspectors could extend their influence in daily working interactions to optimise environmental design solutions.

INTRODUCTION

Building control inspectors (BCIs) are part of the construction process on all construction projects in the UK, with the possible exception of very minor domestic works. They are involved in schemes ranging in value from many millions of pounds down to the individual homeowner tackling a do-it-yourself internal re-arrangement. Despite their ubiquity, there has been surprisingly little research with these professionals. Given their pivotal role in assessing compliance with building regulations, understanding their potential for instigating change is essential for the industry to become more sustainable. The objective of the current study was to investigate the role of building control inspectors and their power in facilitating sustainable construction. The duties of the building control inspector and the process by which the responsibilities are discharged are first outlined, before discussion of the relevant literature. A theoretical framing of power is then described before the method and findings of the study are presented and discussed.

The building control process

In England, aspects of a building's performance are mandated by a set of legislative instruments, collectively known as building regulations. These are set out in fourteen parts, including structure (Part A), fire safety (Part B), ventilation (Part F), energy efficiency (Part L) and access (Part M). The duty of the BCI is to assess compliance with these regulations. The process of building control proceeds either via plans' inspection or building notice. For projects with design plans (typically all projects with the exception of some minor domestic works), the plans are submitted to Building Control prior to commencement of work on site. The BCI conducts an assessment of the plans against regulations, followed by site inspections to assess the work against plan as construction progresses. Alternatively, for small projects, a building notice may be given and the BCI carries out a number of site inspections to evaluate compliance with regulations. In both cases, successful compliance results in the BCI issuing a certificate on completion, which can be important for gaining insurance or mortgage funding. The building control function was originally discharged by local authorities. From the mid-1990s however, private firms were permitted to offer building control services, within a strict framework of accreditation in which evidence of knowledge, capacity, experience, training and insurance are regularly audited. Such firms and their qualified inspectors are known as 'approved inspectors' and the building control function of assessment of compliance is now carried out by approved inspectors and local authority inspectors.

Building control in the literature

Research studies which have contributed to knowledge on building control have tended to focus on building regulations, particularly on their effectiveness as legislative instruments. Previous work has examined fire safety regulations (Bright 2007), general compliance with a focus on health and safety (Baiche, Walliman and Ogden 2006) and energy efficiency (Part L) compliance in research exploring sustainable construction (Bell, Smith and Palmer 2010; Pan and Garmston 2012). There has been consensus in earlier studies that Part L is viewed by BCIs as less important than other regulations (Cox 2006; Williams and Dair 2007; Fischer and Guy 2009). Indeed Boardman (2007: 369) argued that Part L was not seen as "worthy of enforcement" by BCIs. However, such studies were conducted a decade ago. In the interim, the UK Government has enshrined emissions targets in law through the Climate Change Act of 2008; building regulations (particularly Part L) have become incrementally more stringent and further legislation on sustainability in construction, such as the Code for Sustainable Homes, has been introduced (and recently withdrawn). Lipsky (1980; 2010) has argued that policy is

in fact made by the day-to-day practice of 'street-level bureaucrats', that is, the individuals with responsibility for implementing government policy. Thus an updated investigation with a focus on building control inspectors, rather than on policy instruments, is merited.

Studies on research questions beyond regulations have provided perspectives on BCIs seen through the eyes of other construction professionals. Architects and designers have been found to consider BCIs as a barrier to the inclusion of recyclates in construction design (Chick and Micklethwaite 2004). Contractors and building performance consultants have questioned understanding of Part L regulations among BCIs (Hamza and Greenwood 2009). A particularly bleak image emerged from Fischer and Guy's (2009) study with architects, with some of their interviewees suggesting that BCIs are poorly-paid, under-resourced, lacking in skills (specifically on Part L calculations), with a culture that de-prioritises energy efficiency. However, the perspective from one profession and one study cannot represent the wider picture, and differing views on the role of BCIs were discussed within Fischer and Guy's (2009) own findings and elsewhere. Good and effective relationships between BCIs and site managers (Baiche, Walliman and Ogden 2006) and between BCIs and small builders (Sun *et al.* 2015) have been noted. Although good relationships between BCIs and builders could lead to an informality that threatens standards (Geelhoed *et al.* 2012), flexibility and openness to discussion by BCIs are valued by other construction professionals (Killip 2013). Amongst Fischer and Guy's (2009) architects, some had experience of productive long-term working relationships with approved inspectors, who effectively became part of the design team. The role of the BCI as enforcer of regulations has tended to be taken for granted in previous studies, with Baiche and colleagues (2006) as amongst the few to argue that responsibility for compliance falls to site managers and operatives and that BCIs should be facilitators and certifiers rather than enforcers. In one of the most in-depth studies with building control personnel, in which 59 professionals were interviewed in an investigation of Part L compliance (Cox 2006), the mechanisms by which BCIs can wield power were briefly outlined. Distinction was made between local authority and approved inspectors. Both can write letters as an initial sanction to draw attention to non-compliance and can refuse certification. Approved inspectors can refer a case back to the local authority and the local authority can take a case to court, although this is rarely done. The author notes that these mechanisms of power are rarely invoked and that "gentle persuasion" is the preferred means of progress (p. 4).

Power in social relationships

Despite the focus on weaknesses in compliance in the studies cited, findings show generally high levels of compliance with building regulations, demonstrating that the role of the BCI is by and large successful. However, the implicit assumptions around power as enforcement and the very limited discussion of how BCIs achieve compliance within interactions with other construction professionals ignore long-standing knowledge on the nature of power and influence in social interaction. French and Raven (1959) proposed a model of power in social relationships which has been refined subsequently (Raven 1992) and remains predominant in social research (Fiske and Berdahl 2007). In this model, social influence is defined as a change in an individual's behaviour or belief resulting from the action of another person, the influencing agent. Social power is defined as the potential to wield such influence (Raven 1992). Social power exists in all human interactions and is invariably implicitly recognised. However, typically, some forms of power are assumed to predominate in particular interactions while others are overlooked. Of the six bases of power proposed in the model, the most easily recognised are those of reward, coercion and legitimacy. Power stemming from the ability to reward is self-evident and coercion is its complement – the power to punish. Threats and rewards may be real, as in the power to award or deny certification of building compliance, but may also be

interpersonal – personal approval or disapproval by someone perceived as important to the individual also function as threat or reward. Legitimate power arises, amongst other sources, from a structural relationship, thus the position of building inspector carries formal legitimate power, based on its legislative role, to query, challenge and offer suggestions to others in the design team. Less well-acknowledged bases of power are those of expert and informational power. Expert power lies in the tendency for people to follow the advice of those they consider experts, in the assumption that the expert has greater knowledge. Informational power relies on access to information or reasoned argument. The sixth power base, referent power, relies on the target of influence identifying with the influencing agent, and is not considered relevant here. Thus French and Raven's model of social influence proposes five bases of power which may be available to BCIs: reward, coercion, legitimacy, expert and informational.

The objective of the research was to explore the role of BCIs in relation to sustainable construction. Taking a qualitative approach as appropriate for an explorative study, we did not begin with a priori theory or expectation, in line with recommended practice. In the analysis stage, we identified French and Raven's theory as a useful framework to aid interpretation of the data and we describe it here as background for the reader.

RESEARCH METHOD

In order to explore the role of building inspectors in depth, a qualitative methodology was adopted. The objective was to gain a broad but nuanced account of how Building Inspectors themselves perceived their role. Semi-structured interviews were conducted with twenty practising building inspectors and four senior representatives of relevant professional bodies (the Chartered Association of Building Engineers, the Chartered Institute of Building, Association of Consultant Approved Inspectors, Local Authority Building Control). Half of the participants worked in local authorities and half in approved inspector businesses. The majority of participants were recruited by direct invitation – for the approved inspectors, a list was compiled of all approved inspector organisations. A small number volunteered by responding to a notice on the Planning Portal website. Both businesses and local authorities were selected to ensure a spread of representation across England. No other selection criteria were applied. The interviews were conducted by the second author, lasted approximately one hour and were audio-recorded and transcribed verbatim.

Thematic analysis was conducted on the data - an analytic method that systematically seeks patterns in the data enabling interpretation that is both detailed and rich. The analysis facilitates two levels of interpretation: first, a more descriptive reading, representing a surface level account of the data, and second, a more critical analytic interpretation, in which commonalities and contrasts within the data and beyond are drawn out. At this level, the analyst can draw on previous research and theory to add insights to interpretation. Following the guidelines of Braun and Clarke (2006), the transcripts were read and segments of interest were coded. When all transcripts were coded, the coded segments were clustered into subthemes and then into themes, checking back constantly to the data to ensure completeness and accuracy. In keeping with recognised standards of rigour and validity for qualitative research, data abstracts are presented below to demonstrate transparency and to allow the reader to evaluate the appropriateness of the analysis.

RESEARCH RESULTS

The themes in the data were clustered into three groups: (1) ensuring basic compliance and the limitations of the role, (2) advising and guiding the design team and (3) a broader vision for the role. These themes are first discussed in general before considering their applicability to the participants'

responses on sustainable construction. Verbatim quotations are indicated by participant number (e.g. P3) to protect anonymity.

Basic compliance and the limitations of the role

The participants described the role of the Building Control Inspector as ensuring compliance with the regulations: to ensure "*the building is fit and safe for use*" [P5]. Most emphasised the minimal nature of required compliance and many referred explicitly to the boundaries of their role. They clarified that the building inspector's role does not include design. Although they can exercise judgement and consider novel solutions, they cannot instruct changes that have cost implications. Most saw decisions being driven by others: "*we're not really a decision maker that, I don't think, that can make a lot of difference…contractors and clients and designers have more of a role to play*" [P17]. The sense from many was of the limitations of their role, it being closely aligned to building regulations and with power only to assess (minimal) compliance. These responses clearly considered only the legitimate base of power from French and Raven's (1959) model and perceived this to be a limited form of power.

Advising and guiding

However, an alternative perspective emerged in parallel. A number of participants saw themselves as an intermediary between government policy and industry in terms of knowledge, and spoke of "*pass[ing] information on to builders and designers*" [P16]. Several mentioned "*grey areas*" in regulation, where the requirements were not straightforward, and described their role as helping the client. Some noted their collaborative role on the project team, communicating between different professional silos which included communicating design intent to people on site. They typically dealt with the full range of parties involved in a construction project, including clients (from organisational to private householder), structural engineers, architects, site agents, heating engineers, fire officers, builders and site operatives. A number described one of their main objectives as assisting both design team and client:

> Our primary aim is to get the best possible outcome for the building in terms of the client's wishes and the design team's wishes, at the same time as achieving the highest level of compliance…we have two goals. [P12]

The majority saw their role as including the provision of guidance and advice. Most offered technical consultations at a pre-submission stage, to members of the general public as well as to other construction professionals, and their advisory services continued from the early stages of the project right through to on-site work. Some spoke of negotiating, compromising, "*an element of advocacy and persuasion*" [P7]. A number described making suggestions and offering options or alternative solutions and: "*If, for example they can't meet an aspect of the building, we will give them suggestions*" [P19]. A strong emphasis on interpersonal skills and an ability to communicate and negotiate was evident. Some participants explicitly contrasted the typical approach with an earlier or stereotypical role of 'police officer': "*We need to advise and be advisory because the world has changed and customer expectations have changed. Nobody, a householder, or whatever, will tolerate anybody wielding a big stick from the public authority*" [P7]. Here the participant makes reference to what the social power model would term coercive power and interestingly, the reference relates to the ineffectiveness of this power base.

A few participants recognised the influential nature of the role of building inspector:

> That influence is real… the small to medium sized contractors, they will defer to a building control officer for the simple reason that they want to get a building built … and they will give him his place. [P2].

Another spoke of the significant impact of building control on the sector: "*For the industry, we have a huge impact on the built environment, huge…we're the people that no-one notices…without us, it wouldn't be possible and we make a huge impact*" [P12]. So although the bounded nature of their role was salient for the participants, they also described the guidance and advice they offered and the processes of discussion and communication they used, with a few recognising the considerable influence of their profession. From the perspective of social power theory, the BCI possesses expert and informational power as well as institutional, and the evidence here suggests that these forms of power are exercised by BCIs on a day-to-day basis, albeit often without full recognition.

Broader role

Despite the emphasis from the majority on the constraints of their position, some participants showed a broader vision of the potential of the building control role. Noticeably, a few did not accept the limitation of minimal compliance with regulations, speaking instead about contributing to high quality in construction: "*I think [the role of building control is] to support the construction industry in getting the quality of building construction as high as possible*" [P7]. Others described being pro-active in their approach within the limits of ensuring compliance. Some participants noted the wider role of the building control sector, contributing to British Standards for example, and others saw the potential for this to be expanded and to include input to regulations.

Sustainable construction

Before considering the three themes with respect to sustainable construction, two preliminary points are necessary, regarding the participants' interpretations of the term 'sustainability' and their perspective of the relative importance of regulations addressing sustainability.

Understanding of sustainable construction

The interviewees provided a broad range of responses when asked what they understood by the term 'sustainable construction'. Most referred to energy efficiency and thermal performance. Some referred to flooding, biodiversity, water efficiency, waste and materials. Several saw sustainability in terms of durability, linking the term to high quality, flexible buildings that were useful to their occupants and to society over time. A number spoke about the bigger picture and global context. For most participants then, there was a holistic understanding of sustainability in construction, not restricted to the few aspects addressed in current building regulations.

Relative importance of regulation parts

Participants were asked if all regulatory parts were of equal importance, in order to assess the relative priority of environment-related provisions. There was consensus that compliance with all parts were required but that primary attention may be paid to some provisions. As Participant 12 explained: "*We can't sign a building off unless we're satisfied that every, single building regulation is at a satisfactory standard, but naturally, you get drawn towards certain regulations because of the impact they have*". For most participants, fire and structural safety were the parts that were first mentioned although a few also referred to Part L on energy efficiency as high priority. In contrast, others described the difficulty of communicating the importance of Part L to the client due to its intangibility and complexity. This suggests a somewhat complex take on the regulations by building control inspectors: recognition of the equal statutory footing of all provisions but the experience of an implicit hierarchy of importance influenced by risk and tangibility.

Responses to their role in sustainable construction showed a similarly diverse range to views on the role in general. For some participants, the fundamental role was that of compliance with Part L, and more generally to implement government policy. A number clearly articulated what they perceived as the absolute limitations of their role, seeing no involvement without the existence of legislation: "*The only way building control could make [construction more sustainable] is to get it within the legislation as set standards, otherwise we can't really enforce anything*" [P5].

However, several participants juxtaposed acknowledgement of some power on aspects of sustainability alongside the constraints. For example,

> We can't influence design and we can't influence how things are done, but then when people are talking to us about renewable energies… is guiding them through various options that are available to them. [P9]

One spoke of an "*advocacy role*" in encouraging the client and designer to improve thermal performance so that energy bills were reduced. Another mentioned scope for advice given the flexibility in thermal modelling for projects. So there was reference to influence beyond ensuring that the regulations are met. However, although referred to, in most cases, this influence remained partially unrecognised. For example, one said:

> They could perhaps say in the process of value engineering and so forth that they might want to think about this or … that, but it's nothing that we have any power to enforce, it's all sort of goodwill. [P21]

In these extracts, the participants show awareness of the expert or informational power of their role but appear to acknowledge only the coercive power base – other forms of influence are dismissed as "*goodwill*".

When asked about the contribution that the building control professional could have, participants proposed multiple ways for the sector to facilitate progress of sustainable construction. Reference was made to the ability of building inspectors to "*push the boundaries*" [P9] and to facilitate the introduction of alternative technologies and methods; to apply their knowledge for more holistic solutions, "*to encourage people to think*" [P16]. There was recognition of the potential to encourage others on construction projects to set and achieve higher standards with respect to the environment and generally "*to promote good practice in terms of build and materials*" [P14]. One key informant felt that building control had the potential to influence the industry in general and could encourage development of government policy. Another BCI clearly described the constraints of the role but went on to describe his efforts on a flagship project, intended to demonstrate excellent practice. Thus, despite near universal recognition of the limitations of institutional power of their role, French and Raven's legitimate power base, almost all were deploying expert and informational influence in their day-to-day interactions, and a number were actively looking for other ways to influence the industry.

DISCUSSION

Based on our analysis of interviews with twenty-four building control professionals, the findings suggest that most considered their role in sustainable construction to be limited by the content of building regulations. However, this perspective overlooked the processes by which BCIs in fact operate. In parallel with describing the constraints of their role, the participants also describe informing, advocating, persuading, guiding and influencing, as essential mechanisms to accomplish their job objective.

From the perspective of the social power model (French and Raven 1959; Raven 1992), their responses appeared to consider primarily the formal legitimate power base, that is, the power based on the regulatory role of the building control inspector. Limited comment was also made on coercive power – the power to punish, in this case by not signing off on compliance. An approach based primarily on coercive power was seen to be likely to meet resistance and to be ineffective. An analysis of power bases by Raven and colleagues (1998) found a two factor solution: (1) harsh forms of powers including power from legitimate position and use of sanctions, and (2) soft forms including expert and informational. The responses from our participants recognised harsh forms of power almost exclusively. However, other forms of power were in evidence. In particular, participants referred to informational power in which they proffered suggestions to the design team, and to expert power, in which their knowledge and experience contributed to project outcomes. While on the one hand the participants described how they used these forms of influence, on the other hand, they appeared to dismiss them, in one case describing them as just "goodwill". Research has shown these 'soft' forms of power to be, in general, more effective than harsh forms, with expert power particularly effective across domains (Fiske and Berdahl 2007). A small number of participants appeared to realise the expert power of BCIs and had planned, or could see potential, to drive flagship projects or to influence government policy. For a few, their expert power was consciously incorporated into their daily job, in their attempts to move beyond the minimal requirements of the regulations and to encourage higher standards.

The findings here align with the arguments of Fischer and Guy (2009) on the potential role of the 'intermediary'. Although examining the role of the architect, they proposed the importance of the intermediary, who could mediate not only between the technical requirements of regulations and the design team, but could also mediate between construction professionals. The BCIs here described their relationships with multiple players within the design team and beyond, and referred to conveying knowledge and expertise – about the design intent, about the regulations and about construction techniques in general – amongst the range of project stakeholders. Fischer and Guy argued for the important role of intermediary in sustainable construction to be played by architects. We argue that BCIs are also ideally placed to take on this role. Indeed, BCIs may be better placed given their independent role, not employed by the client, and their frequently greater presence on site.

The findings here challenge earlier research which argued that Part L of the building regulations was seen as less important by BCIs. The participants in this study were clear that all regulations were important and that compliance with all is required. Even if some appear to be primary, the participants noted that, in reality, it is highly unusual for regulations to be prioritised – compliance with all relevant parts must be achieved. As the earlier studies were completed a decade ago, it is possible that understanding of the importance of Part L has developed in the interim. The current study also contrasts with that of Baiche and colleagues (2006) in which the participant BCIs suggested that the regulations were straightforward to interpret. Here, the 'grey areas' of regulation which required the BCI's interpretation were mentioned by several, as was the complexity of Part L in particular. Again, the passage of time and evolution of the regulations may explain the difference in findings.

CONCLUSIONS

The power available to BCIs goes beyond that of the formal legitimate power of the role and the coercive power to refuse certification of compliance on a building project. Although these are the forms of power most often referred to, in reality, the BCI's role in ensuring compliance is typically achieved through expert and informational power, deployed through advice and guidance. There is great potential for BCIs to become more influential in encouraging increasing levels of sustainability through realisation of all of the power bases they wield and how they can use them most effectively. This potential is understood, and acted upon, by some BCIs but could be deployed much more widely. Decades of theory and research on social power point to bases of power and means of effective use which could enable BCIs to leverage the power of their role to contribute more to progress to sustainable construction.

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DESIGN AND IMPLEMENTATION OF A SUSTAINABILITY INITIATIVE FROM THE "INSTITUTIONAL MIDDLE": REFLECTION ON THE ORGANISATIONAL CONDITIONS FOR IT TO THRIVE/OR FAIL

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ABSTRACT

This paper explores the organizational, structural, conditions for the "institutional middle" to thrive in the implementation of sustainability efforts in a High Education Institution. This work combines participant observation and case study techniques, together with linear analysis concepts from Organizational Cybernetics and literature on campus sustainability to analyze the organizational conditions that affect the institutional middle's potential for success/failure in the implementation of sustainability initiatives in a private small university.

The empowerment and recognition of autonomy of faculty and staff are found to be critical for the successful conception and implementation of sustainability initiatives. However, such effectiveness depends on the provision and emergence of adequate organizational structures to guarantee the resilience and viability initiatives born from the "institutional middle".

The case study provides evidence of how the institutional middle can affect the top-down management for both the management of environmental issues in campus and the development of contextualized academic programs. The case study suggests a cost-effective, efficient and high-impact method to design and implement sustainability initiatives in universities.

The case study provides evidence of the impact of adequate organizational structures supporting initiatives from faculty and staff. The organizational cybernetic approach proves to be useful to understand (sustainability) entrepreneurship in the institutional mid

INTRODUCTION

Since the publication of "Our Common Future" (Brundtland, 1987) sustainability has become a major topic of discussion in the private and public sector. The challenge that this new agenda imposed on Higher Education (HE) became compelling as it influenced not just the development of academic contents but the HE institutions' management and ultimately, their environmental behavior. The documentation of this process of adaptation and change is not well documented, due perhaps to the specific challenging operational context, the sui-generis missional nature of HE institutions and their particular structure and forms of governance that differ from those of conventional firms (Bero et al, 2012; Cortese, 2003).

Recently, the increasing literature on campus sustainability describes the change towards sustainability either as a top-down process led by managers, or as a bottom-up movement led by students, with few references to a mixed approach. The top-down approach describes the process as less time consuming whereas the bottom-up is perceived as more robust. Recent cases suggest that a mixed approach as the most desirable and effective implementation scenario (Disterhef et al, 2012; Lozano et al, 2014; Ramos et al, 2015).

Within this context, the description of the role of the "institutional middle" - staff and academics - as a driver of change towards campus sustainability has been documented describing the role of academics and staff as intrapreneurs; identifying strengths and obstacles for their action and recommending strategies to foster middle-up initiatives (Brinkhurst et al, 2011). From this last perspective, the aim of this paper is to contribute to the knowledge of the organizational (structural) conditions that affect the viability and emergence from the "institutional middle" of a process of organizational change for management sustainability (OCMS) in HE.

Background

Sustainability has become a source of inspiration for bottom-up activities in many institutions (e.g. People and planet – Go Green/Going Green initiatives[1]; OIKOS[2]) and core for some more formal and top-down approaches such as the Magna Charta Universitarium (1987); the Talloires Declaration (1990); Copernicus – Campus (1993); the Luneburg Declaration on Higher Education (2001); the IUA-UNESCO Global Higher Education for Sustainability Partnership (2002) and more recently the International Sustainable Campus Network (2010), and the Decade of Education for Sustainable Development 2005-2015 proclaimed by UNESCO (UNESCO, 2010).

[1] People and Planet is a spin-off of the Third World First initiative. Its campaigns include programs such Go Green and Going Green grouping more than 60 Universities mainly in the UK.

[2] OIKOS was created by students at the St. Gallen University in 1987 with the aim to include conferences and workshops related with environmental issues in the academic programs of Business Management and Economy. In 1989 they created the conference in Ecologic Management and transformed one organization with more than 300 associated enterprises, starting an industrial re-engineering process towards sustainability in the Swiss Industrial sector.

These schemes invite the HE institutions to act towards the implementation of sustainability measures, particularly since the educative institutions become subject to the effects of environmental regulation (Noeke, 2000). In response to these challenges the Higher Education Institutions have implemented actions, predominantly toward greening their campuses, either through formalized environmental management plans following the ISO 14001 structure – or any other certified scheme – or with the use of informal mechanisms as documented by Wells et al (2009); von Oelreich (2004); Conway et at (2008); Clarke (2006); Spelleberg et al (2004) and Clarke and Kouri (2009). In general, these responses are aimed to green the campus by reducing consumption of paper, energy and/or water or implementing architectural changes to gain in energy/resources efficiency, leading to financial saving (Nicolaides, 2006; Camacho, 2005, 2007).

On the identification of the actors of this change process, Heferly and Clarke (2009) recognized senior managers and students as the change makers that drive the adoption of sustainability initiatives in HE; neglecting the role of the "institutional middle". More recently, from the observation of the nature of the change process Brinkhust et al (2011) and Disterheft et al (2012) recognized the implementation of sustainability in HE as a complex process that involves many organizational levels and actors; where the "institutional middle" – academics and staff – are critical for institutional change due to their long-term presence in the institutions and their brokerage capacity linking diverse organizational levels (including students and top managers). In this context, academics and staff have been described as "organizational innovators and intrapreneurs" (Lozano, 2006; Brinkhurst et al, 2011).

Organizational Change and Campus Sustainability

The change process can be described as the movement of an organization from a certain status to a new future state; involving modifications that may occur at different scales (e.g. minor, incremental, transformative/radical); at different organizational levels (individual, teams/divisions, institution) and affect and/or being expressed in the cultural, political, processual and/or organizational systems (Dawson, 1994; Dopplet, 2010; Cameron and Green,
2009).

To make sense of this complexity some classifications for this process have been suggested. For instance, according to intervention in the change process Bennis et al (1969) identify three types of organizational change: 1- radical intervention: organized and strictly top-down with emphasis on conflict management; 2- serendipitous change: described as a continuous and unpredictable laissez-faire process of adaptation to changing conditions; and 3- planned change: that offers guidance without being too restrictive or too serendipitous. With regard to the existence of a preparatory stage to change, divergent positions also exist. Some authors advocate for the development of the introductory planning stage (Beckhard and Harris, 1987; Cameron and Green, 2009; Kotter and Schlesinger, 2008); while others understand the change process as dynamic, adaptive and emergent - with a start in small individual projects that grow steadily without too much planning (Boiral, 2008; Senge, 2006; Verhulst, 2012).

Closely related to the understating of change as a complex, dynamic, adaptive and emergent phenomena, observations of Organizational Change for Management Sustainability (OCMS)

have been made focusing on soft managerial and control mechanisms e.g. leadership, culture (Doppelt, 2010; Verhulst and Lambrechts, 2013; Ceulemans et al, 2015). Also, observations of the OCMS have described this change process as innovation, intrepreneurship and participative cultural change; offering lists of identified drivers, barriers and key factors that affect the implementation process – e.g. organizational culture, resistance to change, empowerment, communications, power, bureaucratic distance and leadership, among others (Lozano, 2013; Lozano, 2015; Brinhurst et al, 2011; Disterherft et al, 2012).

More detailed observations on OCMS include descriptions of evolutionary social networks and how they reflect the key role of academic and staff in the change process (Kurland, 2011) – but not making a clear correlation with the organizational structure of the HE institutions. Further developments (Hoover and Harder, 2014) define the OCMS as a complex phenomenon where multiple interactions among actors and organizational levels can be identified as key for the organizational change towards sustainable development in HE (AKA: organizational culture; territories, conflict and competition; collaboration; importance of committed individuals; individual knowledge and worldviews; personal characteristics – influence, creativity; interplay between structures and people; dialogue, relationships and networks; locating power and the ability to effect change) suggesting the need for a new methodological alternative - complexity management - to the study of OCMS. Aligned with this last perspective, Lozano (2006) and Sterling (2001) advocate for the adoption of a whole-system approach to better understand and drive the process of change towards sustainability in HE.

Organizational Cybernetics perspective

Organizational Cybernetics was developed as a comprehensive body of knowledge to study (organizational) complexity through the analysis and design of organizational structures, roles, communication and information systems. It was introduced as a Systems Complexity Theory approach inspired in the principles of communication and control introduced by Weiner (1948) and other early cyberneticists from the late 60s and early 70s. The foundations of the Organizational Cybernetics were consolidated and presented as the Viable System Model (VSM), providing the necessary and sufficient conditions of communication and control that create viable organizations (Beer, 1979; 1984, 1985; 1989).

The VSM can be described as a framework/methodology to model organizational structures and the relationships among them (AKA: processes, roles/functions and information flows). Paramount to the VSM modelling and analysis is the understanding of how the organization handles the complexity of both their environment and their own activities. To do so, the VSM suggests as modelling building blocks six constitutive parts with specific roles and functions (Figure 1):

The environment (represented as an amoeba-like irregular shape to denote dynamic change)

Primary activities

1. System 1 – Operational units (circle) directly interacting with the environment – they have the potential to become independent/autonomous business/operative units and have their own management roles/functions (square - 1b)

Secondary/Supportive/Meta-systemic activities

2. System 2 – in charge of coordination and conflict resolution of/among primary activities (triangle)

3. System 3 – Is a management role/function (represented as a small square inside the management box) in charge of the delivery and operations management: budgeting, identification of synergies among the primary activities and organizational identity and ethos enforcement and evaluation of operational effectiveness (observation of the operational "here and now". System 3* (inverted triangle)- Monitoring of operations.

4. System 4- Development Management and strategic planning. Identification, observation, evaluation and forecasting of external variables that may affect the organization's viability (observation of the organizational and operational "there and then" - represented as a small square contained in the management box between S3 and S5).

5. System 5- Definition of the organization's ethos, identity and policy (represented as a small square inside the management box).

These Systems (1 to 5) deployed in a recursive structure, facilitate the understanding of how the organization balances complexity among its different components; how the organization unfolds creating a fractal structure that describes (and manages) the complexity of the system and ultimately, the communication, coordination and control mechanisms that provide organizational viability (Hoverstadt, 2009). This mapping of the different systems - their connections and fractal structure - can be compared against the theoretical VSM allowing the identification of organizational pathologies (Beer, 1989; Schwaninger, 2007; Espejo, 2008; Hetzler, 2008, Perez-Rios, 2008, 2012; Hoverstadt, 2009; Espejo and Reyes, 2011) and the design of systemic and structural corrective measures.

The VSM has been proposed as a tool to guide organizational change (Caspel, 2011) and increasing literature documents the use of VSM in organizational change - related with consultancy projects - with observations on specific phenomenon as emergence, resilience, self-organization and viability in different organizations (Espinosa et al, 2015; Cardoso, 2011; Cardoso and Espinosa, 2014; Espinosa et al, 2011; among others). In this context and related with OCMS the VSM was used by Knowles and Espinosa (2009) and Knowles (2010) to design a participative bottom-up Environmental Management System where it proved effective to diagnose and accelerate the rate of cultural change and acceptance in the implementation of a set of environmental policies in one HE institution.

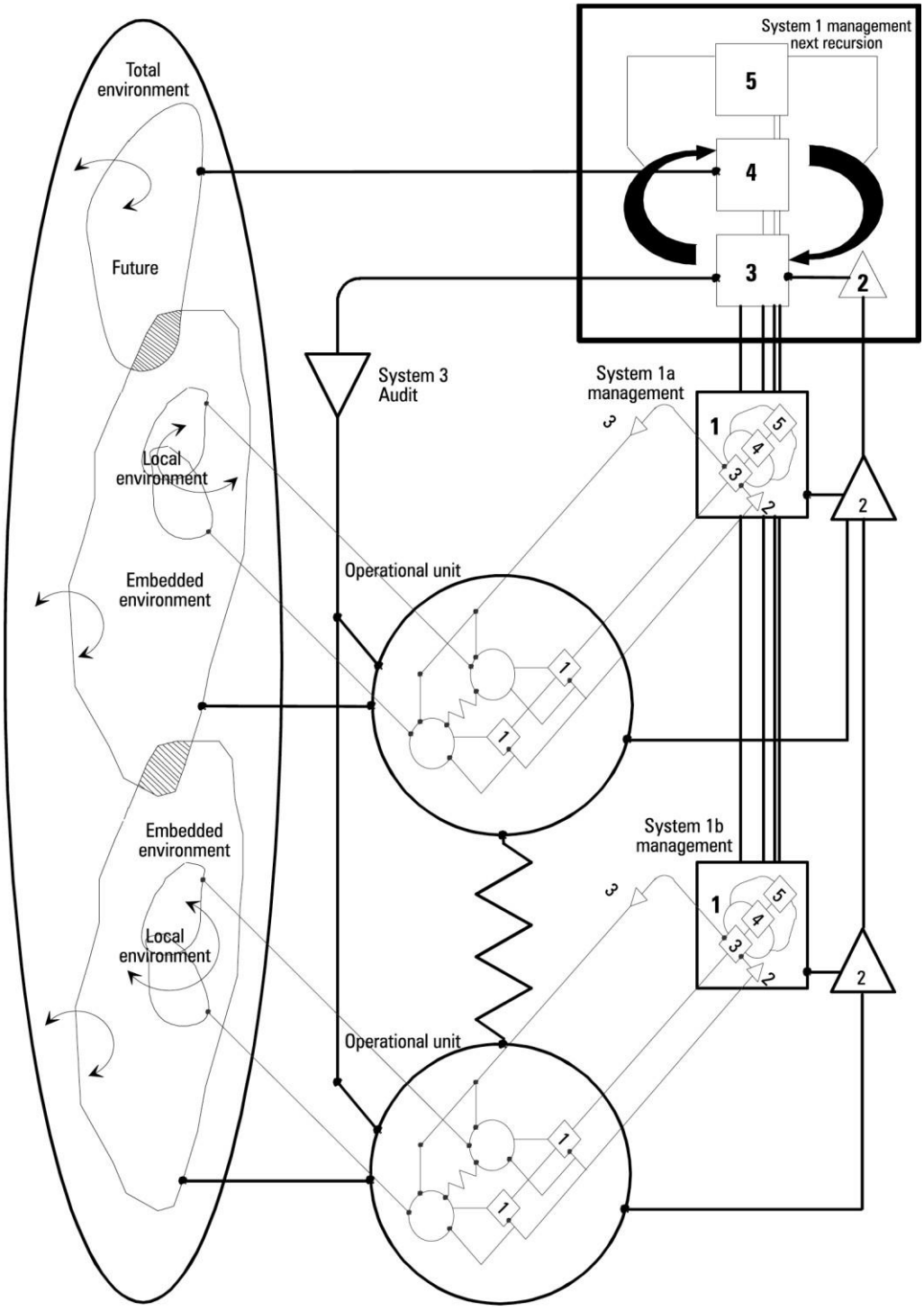

Figure 1. VSM. From Beer (1989). The distribution of the systems 1-5 is represented with the ideal suggested connections that provide viability. Notice the connection of the operations (S1) with the environment and the recursive structure embedded each System 1 where the same architecture is observable - a complete VSM with its systems 1 to 5 inside each S1

METHODOLOGY

The case study methodology was adopted to consolidate the information from interviews to key members of the HE organization who actively participated in the creation and implementation of the sustainability initiative. Documents (mostly minutes from Deanery meetings) of the HE institution describing the general environment of the organization - structure, general performance, etc. - were collected as well as reflective notes from the researchers during their intervention as actors of the observed emerging sustainability initiative.

This information was codified and organized to create a case study aimed to gain understanding from the researchers' experience in the design and implementation of a sustainability initiative in a small private university in Colombia (described as "The U" in this paper) from 2003 to 2007 and 2010 to 2015; in alignment with Yin (2003) about the use of this methodology to describe a contemporary phenomenon within a real context. The case study is relevant as it was the first initiative born in the "institutional middle" and the first and most successful development of an institutional program for sustainability in the HE sector in the country at that time.

Simultaneously, a combination of methods of data collection was used (interviews, focus groups) to triangulate and identify key actors and (organizational) events (Yin, 2003; Eisenhardt, 1989). To create a more complete and updated picture of these events, interviews with identified key actors in different stages of the project were made to gain a deep understanding and an updated description of the organizational context of the sustainability initiative up to its current situation in 2015.

These datasets and rich descriptions where contextualized and analyzed from an Organizational Cybernetic perspective using the Viable System Model (Beer, 1979, 1984, 1985) as this methodology/theoretical framework builds around the operative functions (systems 1) becoming an ideal instrument to observe the role/function of the "institutional middle" from a structural perspective; aiming to identify organizational conditions that influence the emergence and ultimately the viability of sustainability initiatives in the case study. The VSM modelling followed the steps suggested by Espejo el al (1999), with special consideration to the steps: structural modelling and understanding the unfolding complexity that focus on the description of the organizational structure and connections between roles and functions inside the organization. The system in focus was the group of academics based in the faculty of Agro- industrial management where the HE sustainability project was created.

RESEARCH RESULTS

"The U" was created as a vocational institution with a family-business structure (top-down, hierarchical; where the key directive roles where performed by members of the same family, e.g. Rector, some Vice-chancellors and some Deans) in the early 1980s, it aimed to provide qualified workers to the growing banking industry in Colombia. Soon after its creation "The U" developed by demand different schools and faculties in areas such as accountancy; banking and finances; business management; international business; Agro-industrial management; marketing; tourism & airlines management and media & communications; spreading out some elements of control but preserving a rigid top-down hierarchical structure.

With the arrival of the 21st century the environment induced "The U" to upgrade its status to university; implying changes such as the restructuring of schools and faculties, the redesign of academic programs and the implementation of research activity.

Among these changes, by 2002 (figure 2) the faculty of Agroindustry Management was considered redundant. The U was under the scrutiny of the environmental authorities due to the location of the campus in a protected area (forestall reserve) and it needed to address to the new regulations derived from the signature of the Clean Production Act that made compulsory to all HE to include a module on Clean Production in all the Engineering programs. During this period, to adapt to the new organizational realities the head of school (*A*) and the principal lecturer of this faculty (*B*) introduced the concept of sustainability in the campus, starting with the design of a general lecture on sustainability and management for the Business School and the publication of the first paper introducing the topic in the University and the academic community in the Bogota (Boada, 2002).

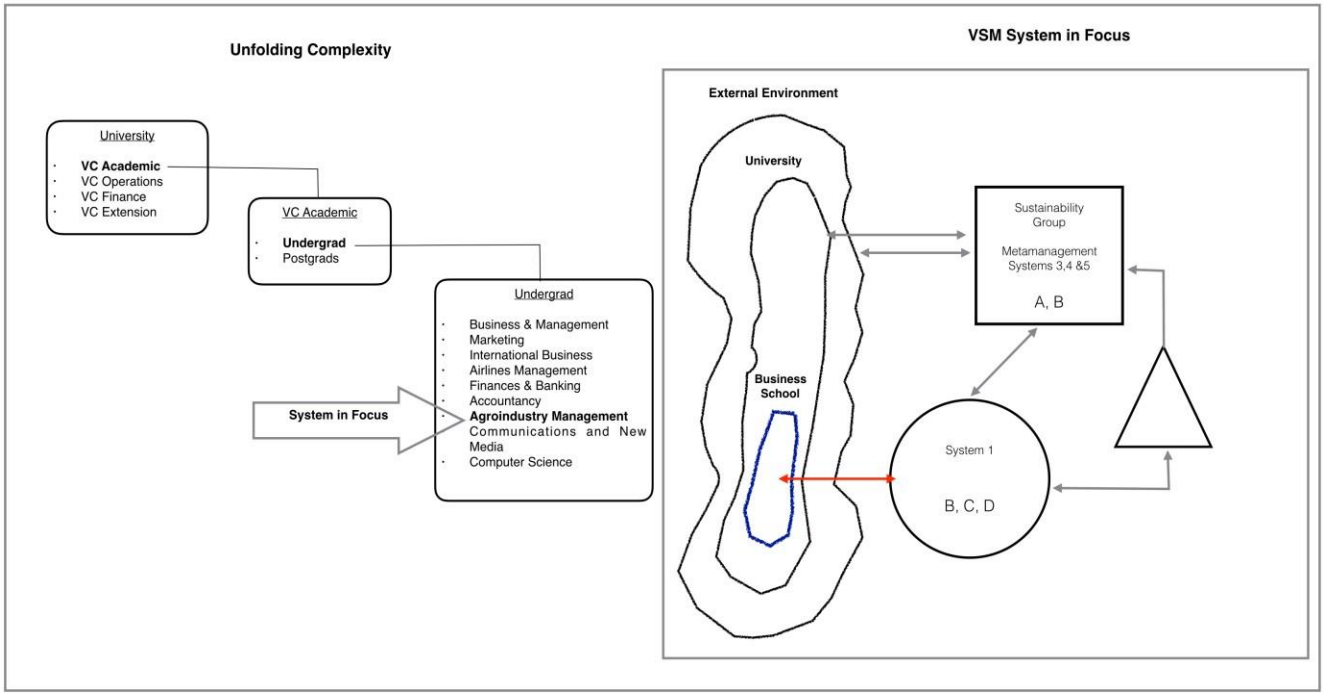

Figure 2. **VSM of the sustainability group in 2002**. Notice the existence of 3 levels of recursion – unfolding complexity, (left side of the figure) and the presence of all roles/functions that provide viability according the VSM (S1 to S5) in the system in focus (the emerging sustainability group).

In 2003 the Faculty of Agro-industry Management was definitely closed and the remaining faculty multidisciplinary group[3] was re-assembled as a thematic group (Sustainability Group) to develop specialized modules, initially for the Business School[4,5,6] - aimed to provide a business- oriented view on sustainability.

[3] The core group was composed by former staff members of the Faculty of Agro-business Management and was constituted by professionals in Biology, Biochemistry and agro industrial engineering (Individuals *A, B, C* and *D*). Later additions of experts in International Business, Biology, Business Management, Marketing, Industrial Engineering, Economy, Law. Communications and New Media and Philosophy (individuals *D, E, F, I, I, J, K, L, M, N*).

A continued as manager at head of school level preserving connections with peers and upper levels of recursion (Heads of School, Deans and VC academic). The delivery of these modules in all the programs of the business school consolidated the connections with that faculty. Other faculties became interested by the customized design of these modules, supported by a constant stream of publications relating sustainability concepts with the ethos of the business school (e.g. Boada, 2003, 2003b; 2004, 2004a, 2004b, 2007; Camacho, 2003, 2007a, 2008,
2013; Boada, Rocci and Kuhndt, 2005; Mont and Boada, 2005; Mont and Boada, 2008) and links with key national and international institutions related with sustainability and business (e.g. Wuppertal Institute; Lund University; Club 10; WBCSD, CECODES).

In 2004 a recently created Research Department provided instructions to all the Schools and Faculties to develop applied research. In response, the sustainability group devised a zero budget-short term-high impact research plan of participative research involving students from the Business School. The scenario for this research was "The U" itself; consequently, the first research project was the Environmental diagnostic of the Campus in cooperation with other vocational institutions, followed by a second research project on Environmental Management Systems (EMS) in Universities culminating with the design of the EMS of the University (Quintero and Camacho, 2004; Camacho, 2003, 2004, 2005, 2007b; Avendanno et al, 2004; Camacho and Cardoso 2010a, 2010b; Camacho and Mejia 2011). From this period the definition of roles and functions that satisfy the structure and criteria for viability as defined by the VSM are noticeable. Mechanisms of coordination and monitoring were set in place as the informal creation of thematic groups to deliver modules in different schools/faculties through an organic and adaptive process of recruitment of new team members (clearly definition of autonomous system 1); the nomination of *C* as general coordinator (system 3); the role of *B* (charismatic and transformational leader) as principal lecturer leading the general development of content and developing contacts with several external partners - together with *A*; the role/function of *A, B, C, D* as the main team defining the identity and policy of the group (system 5). In this stage *A* was also key in the development of solid contacts with the Deanery, advertising the activity of the group at the higher recursive levels of the university (Vice-Chancellor, and informally to members of the board of directors) and particularly gaining support from the VC-academic.

Consequently, at the beginning of 2005 and due to the impact of these short-term research projects and the development of specialized modules that provided "The U" with a unique profile; sustainability was included as one of the main pillars of the strategic plan of the University 2005-2010.

[4] Man and Environment: This module covered basic concepts of ecology, systems thinking and historic and contemporary effects of human/industrial development on the environment.

[5] Environmental Management: This module covered the evolution of environmental management tools AKA: UN/Clean Production Handbook, BS, ISO 14001/EMAS II Environmental Management Systems

[6] Management Tools for Sustainability: This module offered a customized version of the Balanced Scorecard (BSC) for sustainability; the Life Cycle Analysis (LCA); Material Input Per Service Unit (MIPS); the SAFE-COMPASS (Sustainability Assessment For Enterprises – Companies and Sectors in Path for Sustainability); and concepts such as the Extended Producer Responsibility (EPR), Corporate Social Responsibility (CSR), principles of Strategy in Green Marketing and the introduction to Product-Service Systems - all in cooperation with the Wuppertal Institute – Germany and CECODES - Colombia.

Once this “institutional middle” initiative gained recognition and support from the top management of the University the next step was the implementation of some of the programs suggested in the design of the EMS, giving priority to the ones related with the academic functions of the University. Thus, the first actions were the development and introduction of customized compulsory modules on sustainability for each of the Faculties and Schools of the University (table 1) and the implementation of operative planes described in the designed EMS for the university (AKA: Energy Management, Waste Management, Greening Infrastructure, Landscape Management, and a task force to enhance relationship with environmental agencies) all of them under initiatives of participative research, and others under the direct administration of academics from the sustainability group hired for such purpose.

FACULTY	MODULES
Business Management	Man and Environment, Environmental Management, Management Tools for Sustainability
Industrial Engineering	Man and Environment Environmental Management Cleaner Production and Environmental Management Systems
International Business	Man and Environment Management Tools for Sustainable Development
Marketing	Green Marketing and Strategy
Tourism and Airlines Management	Man and Environment – Eco-tourism
Communication and New Media	Man and Environment – Communication for development
Law	Environmental Law

Table 1. Sustainability modules delivered in the faculties of the University.

The level of complexity of the operation under control of the sustainability group generated high levels of specialization of functions for some group members (figure 3); implying high differentiation in the construction of links in and outside the University as well as the redefinition of levels of autonomy for some working groups. For instance: *C* (authoritarian leader) was assigned to the general coordination (VSM- S2), and the leadership of the implementation of some of the EMS programs; *D* (transformational leader) took over the leadership of the development of academic content and scientific production; *E* was hired to administrate the EMS programs that demanded co-management and close coordination with the VC-operations and could not be delivered under the participative research scheme; *B* specialized in scientific production and development of key external contacts; and *M* and *O* started a consultancy unit. In general, almost all team members started to participate actively in academic activities related with sustainability in HE outside “The U”.

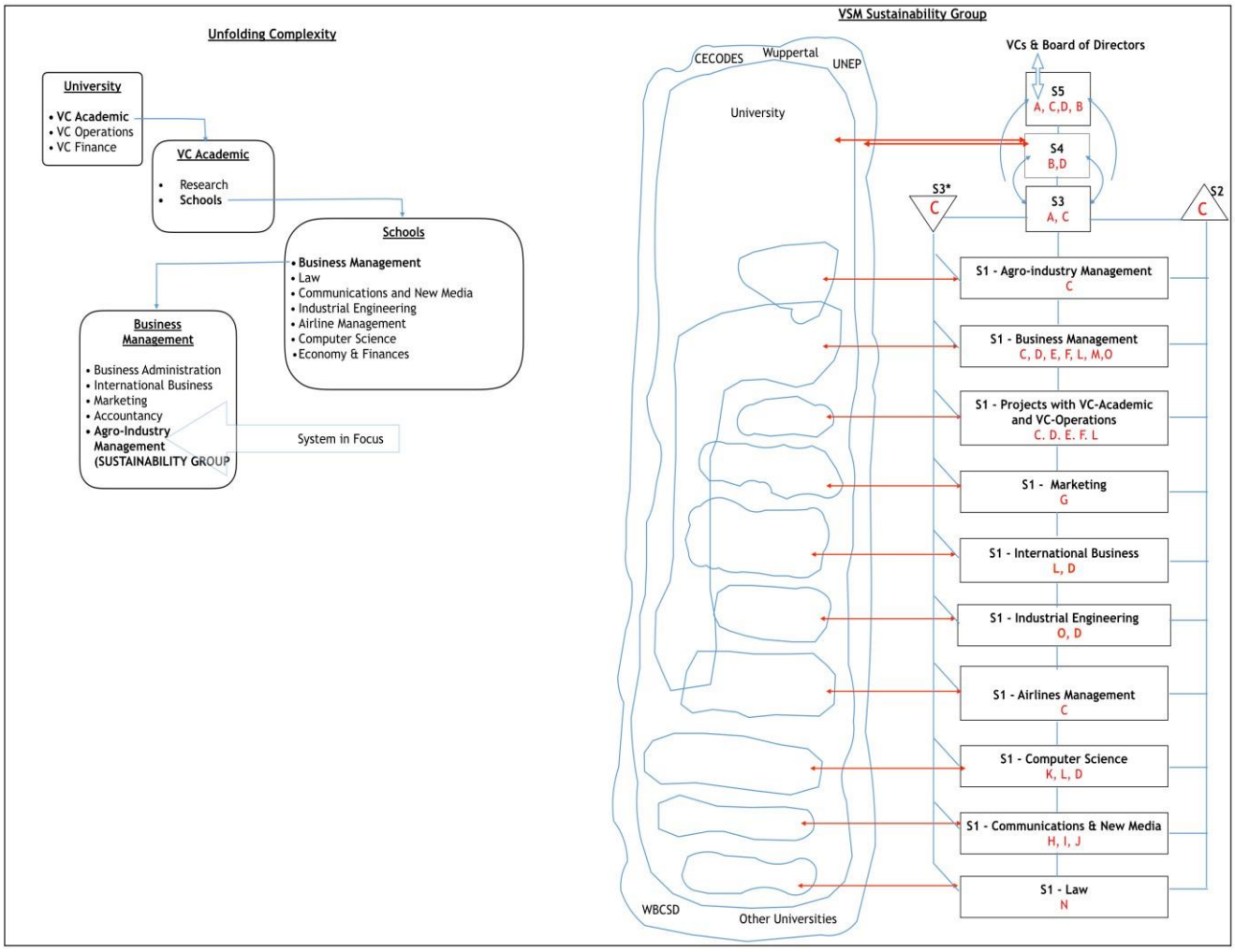

Figure 3. **VSM of the sustainability group 2005**. Notice the addition of a recursive level in the organization and the increasing number of S1 – increasing complexity and diversity of roles/functions within the sustainability group.

In 2007 a new management, with a different ethos, took over "The U" and started an aggressive market-oriented expansion, both nationwide and internationally. This expansion changed the priorities of "The U" and induced a new restructuring process oriented to reduce costs, mostly via standardization and escalation of modules. In consequence most of the customized sustainability modules disappeared and just the core generic modules[7] remained.

As a result of these changes some members of the group migrated to other universities (*B, N, I,J*) and others were relocated in different groups (*A* - to lead research; *O* - to join the VC- operations; *D* - to lead research in a different faculty; *L* and *F* to act as researchers in a different faculty.

As a result, *C* took over the leadership of the remaining sustainability group and relocated roles and functions to respond to the reduced modules and areas of activity. At the end of that period *ER*"The U". The resulting structure of the group at 2008 can be seen in figure 4.

[7] The core modules in sustainability were Man and Environment (to all students), Environmental Management (for engineering) and Management for Sustainability (Business School).

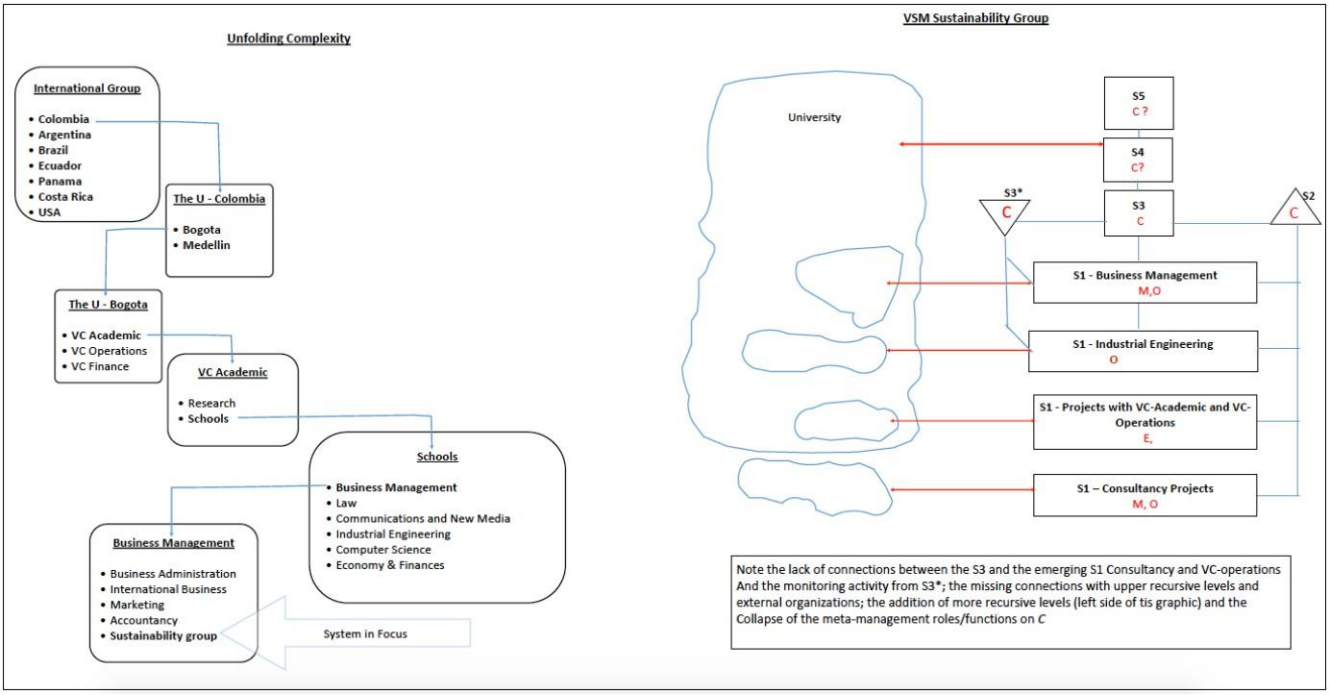

Figure 4. VSM of the Sustainability Group 2010. Notice the reduction of S1, The addition of 2 more recursive levels in the organization, the lack of mechanisms of control in the emergent S1 and the collapse of the all the meta-management roles/functions on *C* and its lack of connectivity with upper levels of recursion.

By 2010 once the process of internationalization and growth stabilized, the institution reassumed its agenda in sustainability. Thus, a top-down, hierarchical structure was set in place, from the VC-operations, looking forward for the ISO 14001 certification for the campus. As a result, some programs were revamped through the provision of additional resources and the execution of small research projects (e.g. Camacho and Cardoso, 2010: offering a comprehensive review about the evolution of and global context of the policy framework underpinning Environmental Management in HE; Camacho and Mejia, 2011; offering a case study describing an environmental program for the redevelopment of the green areas and soil regeneration in "The U" campus). However, by 2011 the sustainability group formally ceased to exist, and just the remaining EMS programs under direct control of the VC-operations were still active.

DISCUSSION

The design and implementation of a OCSD described in the case study follows the descriptions documented by Boiral, (2008); Senge, (2006) and Verhulst, (2012): a small, almost individual, project that grew organically without much planning. The case observed also followed patterns of adaptive behavior where charismatic leadership (Individual *A*) played a crucial role in the development and growth of the sustainability initiative, close to what was registered in other cases by Lozano (2013, 2015) where attributes of the communication network, empowerment and leadership configured a case of intrapreneurship.

In the observed case study, serendipity happened as: 1) the background of the key/founding members of the sustainability group (individuals *A, B, C, D, E*) was closely related to Natural Sciences (Biochemistry, Agronomy, Biology, Marine Biology) facilitating the communication, the creation of a common mental model and conceptualization of ideas towards applied

From the organizational perspective, yet being generated in the "institutional middle" - without inputs from students or the top management- the sustainability initiative was led by a upper middle manager (*A* - Head of School) with key connections with peers and top managers (VC-academic, Board of Directors, Deans, Heads of School). This reduced the bureaucratic distance despite the constantly increasing number of (administrative) recursive levels. It also made fluid the process of pitching as well as the recognition and validation of the group as soon as it generated results with high impact (academic & research products).

These advantages disappeared when *A* migrated to other departments and eventually left the University and the replacement *C* took over, not having the same connections and operative capacity to liaise with the upper management of "TheU" increasing the bureaucratic distance.

From a Complexity Management Perspective, the VSM representation (figure 2) shows how from the first stage of development (2002) the group created clear distinctions between operative and managerial roles/functions: S1 delivering two specialized modules; S2 to coordinate the activity of academics; S3 & 3* providing resources, developing internal synergies and alignment with the ethos/identity of the group, defined as an anthropocentric view of sustainability in accordance to the Identity/Ethos of the University and the faculties served at that moment; S4 developing key external contacts to monitor cutting edge trends on applications of sustainability in business management, (e.g. Lund University, Wuppertal Institute) scanning for new trends in sustainability relevant to the activity of the group; S5 defining the identity, ethos and policies for the group in alignment with the ones of "TheU" – developing close connections at higher and lower recursive levels (top/senior managers and students).

As the group's activity grew, the sophistication of the operative systems (S1) followed, originating several specialized S1; all adequately interconnected, autonomous and coordinated through the assignment of a team member for such function.

It is also important to recognize the key role of *B* in his role/function of S4 developing contacts outside the University with key partners both nationally and internationally.

In the peak of the group activity (2005-2007) several highly specialized functions emerged but in retrospective, it was evident that despite satisfying the conditions for viability, having in place all the VSM subsystems and connections, there were issues that threatened the group resilience: 1) "The U"cultural change with the imposition of a new ethos and institutional project; 2) structural change: the addition of more recursive levels adding bureaucratic distance; 3) lack of resilience/ structural equivalence inside the sustainability group: the lack of individuals at the same structural/organizational level with similar connections, for the key members of the group (e.g. *A, B, C, D*). Particularly the lack of structure equivalence for *A, B* and *D* was critical. Once *A* was removed, the group lost connection with senior and top managers; with *B* leaving the group lost contact with key organizations and when *D* left, the group lost the complex, binding intellectual links and the academic leadership. These withdrawals threatened the group's adaptability and cohesiveness, finally conducing to the collapse of the group's operative capacity. 4) The emergence of new operative units (S1: design and implementation of an EMS with specific actions in cooperation with the VC-Operations in the campus of the University and a consultancy unit). The lack of early recognition of these emergent S1, eventually as a new recursive level inside the sustainability group, conduced towards a lack of control and coordination and communication mechanisms, necessary to manage

the increasing complexity of the hectic activity of the group. 5) The withdrawal of *A, B* and *D* left *C* single handing the VSM S2, 3, 4 and 5, clearly overwhelmed as all the meta-management functions collapsed in a single person. 6) Lack of awareness and reflection on the internal structure of the group (double loop VSM S3-4 and S4-5). It can be assumed that the lack of structural equivalence, the threat to the resilience and ultimately to the viability of the group was never noticed due to the lack of awareness and reflection inside the group on its own organizational structure, due perhaps to the adaptive/reactive nature of its planning and the lack of knowledge and tools to do so at the time.

CONCLUSION

This paper contributes empirical evidence on the importance of the understanding of organizational structures for intrapreneurship and the development of key connections in the emergence and consolidation of OCSD.

In VSM terms, the quick development of connections at higher recursive levels of the organization (top management) seems to be crucial, particularly to gain recognition for emergent initiatives on sustainability. F o r this validation/recognition to be effective, it should be followed by the delivery of tangible academic impact and results (e.g. impact in the curriculum, publications, results from research activity). The case study documented in this study suggests that such tangible products can be generated with little effect on the budget of the HE institution and be aligned with the current workload, profile and deliverables of the staff involved in such initiatives.

From a methodological perspective, the VSM seems to be an effective framework to interpret and contextualize information from complex datasets to analyze organizational structures, their evolution, viability and resilience. This observation suggests that future OCSD and initiatives to design and implement sustainability projects from the "institutional middle" should consider the use of the VSM to monitor and guide the process/project on real time within a context of complexity.

The case study confirms the importance of empowerment, recognition, serendipity - good timing - and autonomy of faculty and staff as critical conditions for the emergence and implementation of OCDS/sustainability initiatives from the "institutional middle". However, such process is highly sensitive to the development and maintenance of supportive organizational structures (AKA: VSM subsystems 1-5) and the early recognition and support from top management.

The paper in general suggests the need for additional research on the attributes of the organizational structures required to provide viability and resilience to OCSD in the HE sector as the results presented are limited to a single case study. In addition, the use of unconventional frameworks to address complexity was explored, however, additional evidence of the effectiveness of such tools/frameworks (AKA: VSM) is needed.

Practical Implications

The case study provides empirical evidence of how the "institutional middle" can affect the top-down management with positive repercussions for both, the management of environmental issues in campus and the development of contextualized academic programs with strong content in sustainability. The case study suggests a cost- effective, efficient and high-impact method to design and implement sustainability initiatives in universities.

This study also provides evidence about the importance of structural equivalence to provide resilience and viability to emergent organizational structures (from an organizational perspective).

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Sustainable Practice and Infrastructure

STABILITY MODEL FOR ABNORMAL LOAD TRANSPORT

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Keywords: stability, safe transport, abnormal indivisible load, modular trailer.

ABSTRACT

The complexity, size and weight of components and machines are growing constantly in many industries. Each of these items need to be transported safety and efficiently by road, rail or water, taking into account the impact of aspects such as wind loads, road attitude and street furniture. For example, the length of the wind turbine blades and the weight of power transformers in the energy industry are indicative of the issues faced by the transport industry. This paper presents a flexible mathematical model able to determine the stability of Abnormal Indivisible Loads (AILs) which are transported by road. The model has been developed taking into account the mechanical properties of the trailers, the load properties and the potential route conditions, such as camber, slope and wind pressure. AILs are objects that cannot be dismantled into smaller parts to be transported. They are frequently moved by means of multi-axle modular trailers which consist of a high tensile steel frame, hydraulic cylinder suspension and steering system. Several modules can be connected end by end and/or side by side to transport voluminous payloads. Modular heavy-duty trailers are a flexible and cost effective solution for transporting heavy loads in the range 44 t to 10,000 t. AILs are a challenge in terms of highway permissions, manoeuvrability and stability. It is noted that the highways authorities, clients and society now demand higher safety standards and sustainable transportation, which implies a better understanding of the transport stability, this being accompanied by data which defines the stability of any load being moved via the public highway. The proposed model increases the accuracy of the calculation and simplifies the calculation process.

INTRODUCTION

The abnormal transport sector is closely related to industries that manufacture bulky and heavy products such as metal castings, wind-generator parts, aircraft components or electricity transformers. These heavy industries constantly demand greater capacity to transport bigger and heavier loads. Frequently, the size and dimensional limits of a product are not imposed by the manufacturing capacity, but by the constraints of moving the product. These limitations can be imposed by infrastructure capacity (e.g. road or canal), regulations or vehicle load bearing capacity. Water transport (sea and canals) is used for some types of load, especially where water access to facilities is convenient for access. The British government pursues a Water Preference policy (Highways Agency, 2012) to reduce traffic congestion and disruption to road users. However, the absence of long-distance internal waterways, such as the Rhine and Garonne in continental Europe, means that most Abnormal Loads still move by road in the UK (Taylor, 2005). That means road transport plays a key role in the transportation of abnormal loads, not alone, but in combination with water transport.

The abnormal road transport industry is focused on ensuring that payloads are delivered safely. There are no specific regulations or sectorial agreements about how to achieve this aim, therefore consequently much is left to the interpretation by the sector, which can lead to unwanted or ineffective situations. Historically, many abnormal transport companies have grown on the basis of their in-depth experience in road haulage and transport. However, to continue growth in these specialised niche markets, transportation companies must be able to demonstrate an appropriate level of formal engineering competence. In this study, the development of an integrated expert system is reported. The objectives of the study are to optimise trailer configuration using a numerical algorithm which is able to formalise the engineering and technical analysis of the transportation problem. This represents a step change in the capability of the sector, including: the introduction of new technology, enhancement of workforce skills, development and embedding of new processes, a change of culture associated with increased engineering and technical formality and innovation.

This study arises from a Knowledge Transfer Partnership project which has been undertaken between Leeds Beckett University and Collett & Sons Ltd. The aim of the project is to develop an algorithm able to determine the stability limits of a truck-trailer configuration using the information provided by client and route characteristics. This new algorithm will impact on the current project management in the company, decision making process and relationship with the clients. Current stability calculations are undertaken by hand, which take time to complete and are prone to errors. A new algorithm, which is described in this paper, enables more loadbearing parameters to be modelled, and results in a more accurate, faster and reliable analysis than current calculation methods.

LITERATURE REVIEW

The stability of heavy trailers travelling along curves has been subject to extensive analysis over the past forty years. (Ervin et al., 1979) examined the yaw stability of tractor-semitrailers through full-scale tests and computer simulations and found a high influence of suspension stiffness and trailer loading in yaw stability. (El-Gindy and Kenis, 1988) researched the influence of axle spacing and load distribution in different configurations. They documented the influence of axle spacing, load and centre of gravity height on the stability and handling properties of heavy trucks. A simulation performed by (Ervin and Yoram, 1986) determined the effect of weights and dimensions on the stability of heavy trucks and revealed that the rollover threshold of different configurations of articulated vehicles ranged from 0.33 to 0.54 g. (BS EN 12195-1, 2013, p. 12195) establish acceleration coefficients to calculate the transport forces. The transversal coefficient given by this standard is 0.5 or 0.6 depending on the lashing method used. Further, (García et al., 2003) calculates the theoretical lateral acceleration when the truck enters a horizontal curve as follows:

$$\frac{v^2}{g \cdot R} \pm e \qquad \text{Eq. 1}$$

Where v is the vehicle speed, g acceleration of gravity (9.81 m/s²), e the camber and R the radius of curvature. However, several external factors, not included in the equation, act on the vehicle under actual operating conditions. The authors found that lateral acceleration recorded in a 5-axle tractor unit, by means of a data acquisition system, exceeded punctually the expected values due to characteristic of the road.

(Gertsch and Eichelhard, 2003) developed a quasi-static and dynamic rollover simulations of a tractor-semitrailer combination using extrapolated experimental data. The aim was to determine when the vehicle rollover might have occurred and to establish a dynamic rollover threshold as a function of the centre of gravity (CoG). The critical lateral accelerations were in the range 0.28 to 0.42 depending on the CoG, whom are in accordance with the values given by (Bernard et al., 1989; Ervin and Yoram, 1986; Winkler et al., 2000) and BS EN 12195-1:2010.

The aerodynamic forces can play an important role in the stability of AILs. These forces are due to the relative movement between the truck-trailer and the air. They come from the body of the truck, the trailer (or semitrailer), the chassis including the suspension, axels, wheels, the load and the gap between truck and trailer. The aerodynamic forces are generally calculated by the drag equation as follows:

$$F_D = \frac{1}{2} \cdot \rho \cdot v_w^2 \cdot A \cdot C_d \qquad \text{Eq. 2}$$

Where F_D is the drag force, ρ is the density of the fluid, v_w is the air velocity relative to the object, A is the area perpendicular to the relative movement and Cd is the drag coefficient. This coefficient is dependent on the geometry and relative position. Thus, the aerodynamic force depends on speed (v_w), dimensions (A) and shape (C_d) of the body. However, the equation is valid only for isolated objects and it is generally used for basic load shapes. An

actual truck-trailer configuration contains other important aspects that contribute to increases in the aerodynamical forces.

Many authors state that the gap between the tractor and the semitrailer is the large contributor to the longitudinal aerodynamic force in commercial tractor-trailer configurations (Allan, 1981; Hammache and Browand, 2004; Mccallen et al., 2000). The gap is commonly expressed in non-dimensional form by $b/\sqrt{A}$, where b is the width of the gap and A the area. Generally, the smaller the gap, then the drag force will be reduced. The drag force due to the gap is zero for small gaps and increases suddenly when $b/\sqrt{A} \approx 0.5$ and stabilizes at 0.7 (Hammache and Browand, 2004; Mccallen et al., 2000). Another parameter that increase the drag force is the yaw angle (Belzile et al., 2012; Hammache and Browand, 2004), especially in trucks with sharp-edge cabs, when operating in cross-wind environments.

Open highways and bridges are frequently exposed to crosswinds that can generate drivability issues in long and tall vehicles, which can result in serious accidents. (Sigbjörnsson and Snæbjörnsson, 1998) presented a probabilistic model using reliability theory, to assess road vehicle accidents in cross wind scenarios. This model is able to reconstruct driving scenarios considering inertial, gravitational, frictional, aero-dynamical, elastic and damping forces; and calculate the probability of an accident using a so-called safety index. Baker (Baker, 1998) described a method to predict accident conditions, that considers vehicle geometry, wind, speed, suspension dynamics and driver reaction. The relation between wind and truck speed for a particular vehicle and site was an essential element of this methodology.

(Bettle et al., 2003) used CFD to study the wind force in a standard North American truck-trailer travelling across a bridge under cross-wind conditions. The geometry of bridge, truck and trailer were taken account as well as the relative wind direction and speed. The authors validated the model with data provided by (Baker, 1998) and (King et al., 1994), and concluded the aerodynamical pressure is relative to wind and truck speed. However, this relationship is sensitive to wind velocity at low truck speeds. Thus pressures can be strong enough to turn over the truck-semitrailer in the studied range of wind speeds.

RESEARCH REVIEW AND METHODOLOGY

A mathematical model was developed in order to calculate the abnormal transport stability. This model is able to calculate the stability of the transport, the load per axle and the oil pressure of the wheel system. It is noted that the model will be improved in future to include more sensitive parameters, such as tyre deflection and ground pressure, which will increase the reliability of the transport safety.
The development of the model was based on a mechanical analysis of the load and trailer. The load characteristics are provided by the client, whereas the trailer properties are provided by the manufacturer. The mechanical analysis has taken into account the previous models available in the literature and common practices in the heavy transport sector (Scheuerle, 2013). It is also important to acknowledge that the reported experience of company personnel was also an important source of information in the development of the model.

The model was implemented into an algorithm written in the statistical language R (R Core Team, 2015). This implementation simplifies the management of manufacturers' data and user input. The model was validated using a full scale proving test carried out at the Collett & Sons Ltd facilities, where deflection data was compared to the output from the model.

RESEARCH METHOD

Modular trailers

This study focuses on AILs transported by road using modular trailers. A modular trailer is a multi-axle trailer that basically consists of high tensile steel frame, hydraulic cylinder suspension and steering system. Its application is for long distance road transport of oversized and abnormal haulages. Modular heavy-duty trailers are a flexible and cost effective solution for transporting various heavy loads. The modules can be connected end by end and/or side by side to transport voluminous payloads. Additional components such as necks, drawbars, ballast, turn tables, etc. serve to assure optimal adaptation to the requirements of each load.

In modular trailers, a central beam and several cross beams offer a high degree of frame stability and thereby optimal loading options. A reinforced loading platform allows extremely concentrated loads to be carried, a hydro-mechanical 2-circuit steering system guarantees that the steering angle can be adapted to the corresponding vehicle combination via the track rods, and The deck of the trailers can be lowered and raised using the hydraulic suspension to receive and release the cargos. The hydraulic suspension is frequently used to level the deck of the trailers, this can be achieved, for instance, by increasing the oil volume of only one side. This is possible because every pendulum axle has a hydraulic cylinder, which is connected with other cylinders to ensure uniform pendulum axle loading. During driving, the hydraulic suspension permits different deflections to be set in each swing axle, as illustrated in figure 1.

Figure 1. Modular Trailer axle compensation. Source: Collett & Sons Ltd.

Modular trailers are the most commonly used devices to move heavy loads by on and off road. Mechanically, they consist of a rigid platform and hydraulic pendulum axles attached in pairs. Each pendulum axle consists basically of two or four wheels (depending on the model), a hinged elbow joint and a hydraulic cylinder, which provides lifting capability and acts as a suspension system. The hydraulic system also allows an even distribution of the cargo load across multiple pendulum axles in uneven ground conditions (see figure 2).

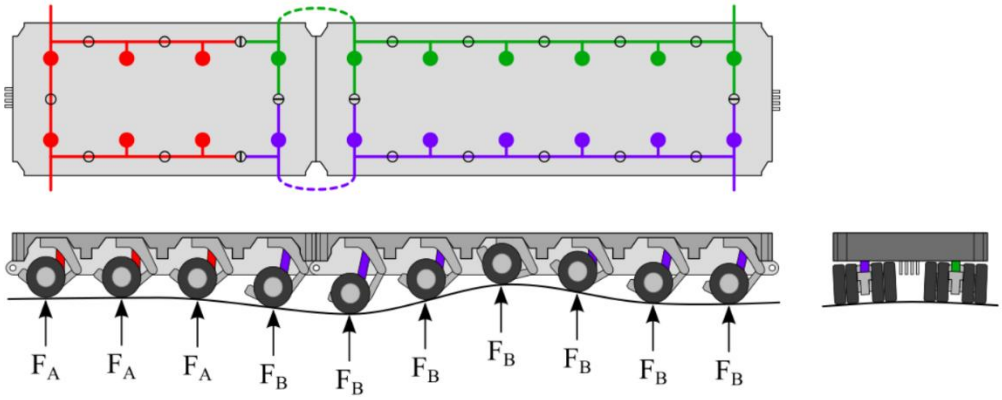

Figure 2. Hydraulic suspension system and even distribution

Stability Area

The number of modules and their configuration depends on the load characteristics (weight, dimensions, etc.) and the route conditions (cambers, turns, etc.). Once the number of axles and the type of trailers have been stabilised, the most important decision is how to group the cylinders to make the haulage arrangement as stable as possible. Each module has a hydraulic system that consists of several cylinders, piping lines and valves which allow the hydraulic connection of several trailers in terms of length, width and options to both connect and disconnect cylinders. Figure 3 shows one configuration of hydraulic system to perform three groups, also called 3-point suspension. In practice, the definition of the groups of cylinders is done through a set of valves provided under the platform of the trailers.

Three is the minimum number of groups possible and it is the most stable configuration. It is possible to work with more than three points, however this study only considers the 3-point suspension model.

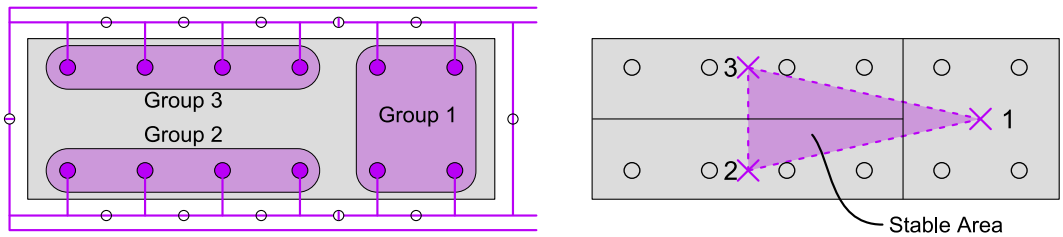

Figure 3. 3-points suspension and stability area

The haulage system is considered to be stable, when the force projection is inside the stability area. There is risk of tipping and/or trailer damage if the projection is outside the stability area. The force projection is vertical, when there are no inertial forces (acceleration, deceleration or turn) and/or wind forces. The corners of the stability area define a plane of the form $a \cdot x + b \cdot y + c \cdot z - K_0 = 0$ that can be calculated solving the following determinant:

$$\begin{vmatrix} x - x_1 & y - y_1 & z - z_1 \\ x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \end{vmatrix} = 0 \qquad \text{Eq. 3}$$

Where (x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3) are the coordinates of the groups 1, 2 and 3 respectively. These coordinates can be calculated analytically or geometrically using the location of the cylinders.

Forces acting upon the Transportation Model

The following forces are considered to determine the stability of the transport model:

- Dead weight (W): the sum the weights of trailers, payload and auxiliary components

$$M = g \cdot \left(m_{load} + \sum_{i=1}^{n} m_i \right) \qquad \text{Eq. 4}$$

- Inertial forces
  - Acceleration/deceleration force:

$$F_A = M \cdot a \qquad \text{Eq. 5}$$

  - Turning force:

$$F_T = M \cdot \frac{V^2}{R} \qquad \text{Eq. 6}$$

- Aerodynamic Forces:
  - Longitudinal:

$$F_{Dx} = \frac{1}{2} \cdot \rho \cdot (V - cos(\alpha_w) \cdot v_w)^2 \cdot A_x \cdot C_{dx} \qquad \text{Eq. 7}$$

  - Transversal:

$$F_{Dy} = \frac{1}{2} \cdot \rho \cdot (sin(\alpha_w) \cdot v_w)^2 \cdot A_y \cdot C_{dy} \qquad \text{Eq. 8}$$

In simple terms, this model considers that all the forces are applied in the centre of gravity. Thus, the total force in the load and trailer is the vector sum of static, dynamic and aerodynamic forces as follows:

$$F_x = F_A + F_{Dx}^* \qquad \text{Eq. 9}$$

$$F_y = F_T + F_{Dy}^* \qquad \text{Eq. 10}$$

$$F_z = -W \qquad \text{Eq. 11}$$

The vector force equation is determined by a point and a vector. The point is the centre of gravity and the vector is the force combination:

$$(F_x + x_{CoG}) \cdot x + \left(F_y + y_{CoG}\right) \cdot y + (F_z + z_{CoG}) \cdot z = 0 \qquad \text{Eq. 12}$$

Quantifying stability

The stability of a transport is commonly measured by the 'tipping angle', this is the minimum inclination of the trailer to overturn. To calculate this angle it is necessary to determine the coordinates of the points O, P, I and C of the figure 3. Due to the limitations of this paper the determination of these points are reported in (Escribano-Garcia, 2016).

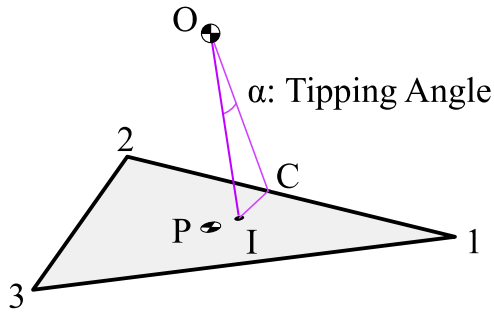

Figure 4. Tipping angle calculation

Points I, O and C defines the tipping angle that is calculated as follow:

$$\alpha_{tip} = acos\left(\frac{|V_{IO} \times V_{CO}|}{|V_{IO}| \cdot |V_{CO}|}\right) \qquad \text{Eq. 13}$$

Where v_{ID} and v_{CD} are the vectors between the points (I,O) and (C,O), $v_{IO} \times v_{CO}$ the cross product, $|v_{IO}|$ and $|v_{CO}|$ is the magnitudes of these vectors.

The most stable point is the incenter in a 3-point suspension. This point is the most stable because the distance to the closest edge is maximum and, therefore, tipping angle is maximum. Therefore, the best colocation of the cargo is one where the vertical projection of the centre of gravity falls into the incenter in a 3-point suspension.

Reactions of the suspension groups

A 3-point suspension is a mechanical system which is statically determinate (or isostatic) because the number of unknown reactions is equal to the number of equilibrium equations. The calculation of the reactions is performed making the following assumptions:

- The reactions (F_1, F_2 and F_3) and the load (W) are perpendicular to the stability plane.
- There are no forces in the X nor Y plane and there is no moment in the Z plane, therefore, there are only three equilibrium equations.
- The system is subject to quasistatic loading, in other words time and inertial mass are assumed to be irrelevant.
- The ground is considered as a completely rigid plane

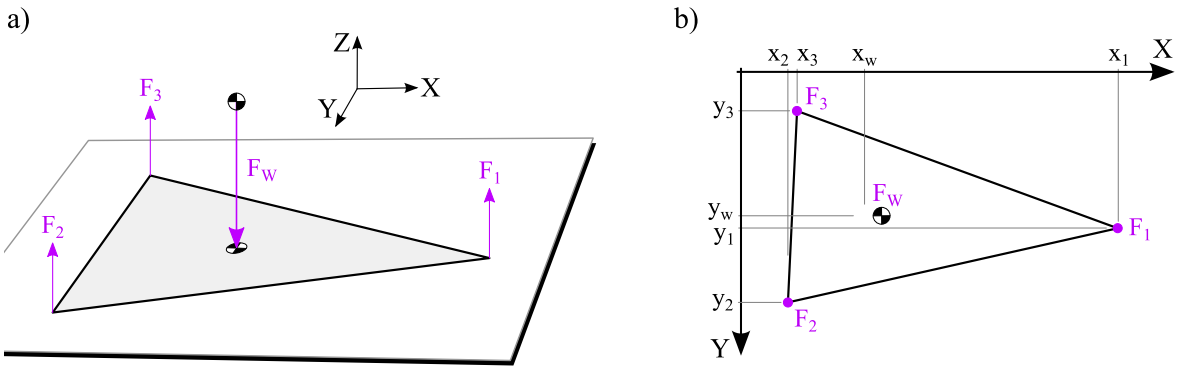

Figure 5. Forces in a 3-point suspension system

Applying the three equilibrium equations:

$$\sum F_z = 0: F_1 + F_2 + F_3 - W = 0 \qquad \text{Eq. 14}$$

$$\sum M_x = 0: F_1 \cdot y_1 + F_2 \cdot y_2 + F_3 \cdot y_3 - W \cdot y_w = 0 \qquad \text{Eq. 15}$$

$$\sum M_y = 0: F_1 \cdot x_1 + F_2 \cdot x_2 + F_3 \cdot x_3 - W \cdot x_w = 0 \qquad \text{Eq. 16}$$

The force in a cylinder ($f_{cyl,j}$) is calculated dividing the force in the group i (F_i) by the number of cylinders of this group (n_i):

$$f_{cyl,j} = \frac{F_i}{n_i} \qquad \text{Eq. 17}$$

Where F_i is the force in the group i, n_i is the number of cylinders of this group. The pressure in each cylinder can be calculated applying the following expression:

$$p_{cyl\ j} = \frac{f_{cyl\ j}}{A_j} \qquad \text{Eq. 18}$$

Where $p_{cyl\ j}$ is the pressure of the oil in the cylinder j and A_j is the area of this cylinder.

RESEARCH RESULTS AND DISCUSSION

In order to validate the model, a series of 13 experiments were carried out at the Collett site facilities. The experiments consisted of three elements: the load, the trailer and lifting crane. Each experiment consisted on locating the load on trailer and the measurement of the pressures of the oil system (see figure 6). The load used was a nacelle, which is a cover housing that houses the generating components in a wind turbine, including the gearbox, generator, drive train and brake. The trailer was a 6-axle SPMT and a power pack unit (PPU) which provides the oil pressure. It was configured as a 3-point suspension and the platform height was set at 1550 mm from the ground level. The load was moved by means of a crane and the trailer remained stationary and in the same configuration.

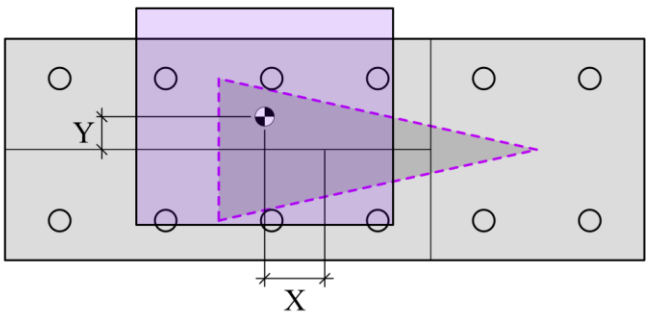

Figure 6. Load provng tests shown in the XY plan view

The same conditions of the experiments were also entered into model. The results from the experiments and from model are summarised in table 1 below. The first five cases have the same inputs in order to determine the variability of the experiments. The mean variability of the pressures measured in these five experiments is the 5.60%.

Table 1. Results

	X	Y	Experimental pressures [bar]			Model pressures [bar]		
			A	B	C	A	B	C
1	0	0	59	61	59	59	58	85
2	0	0	55	62	55	59	58	85
3	0	0	60	61	60	59	58	85
4	0	0	64	56	64	59	58	85
5	0	0	58	63	58	59	58	85
6	0	335	24	97	24	24	93	85
7	0	435	13	108	13	13	103	85
8	675	0	66	75	66	70	69	63
9	675	335	38	103	38	35	104	63
10	675	435	27	117	27	25	114	63
11	1350	0	79	85	79	81	80	41
12	1350	335	47	120	47	46	115	41
13	1350	435	38	127	38	36	125	41

CONCLUSIONS

This paper has presented the mathematical development required to create a model able to calculate the appraisal of complex load stability including the determination of the tipping angle, load per cylinder and oil pressures. The mathematical model considers the mechanical properties of the trailers, the characteristics of the cargo, the route characteristics and atmospheric conditions.

In this paper, the hydraulic cylinder suspension and the definition of the hydraulic groups have been reported. The “stability area” and the “plane of stability” are calculated based on the spatial position of the hydraulic cylinders. Using this data, the loads imposed on the trailer, including the dead weight, the dynamic forces and the aerodynamic forces have been described. These loads are then combined by means of a vectorial sum. The combined force and the “stability area” are then used to determine the stability of the transportation model and the resultant instability or “tipping angle”. Finally, the load per suspension group, load per cylinder and oil pressures have been calculated.

To validate the model, a series of 13 proving tests were carried out with at the Collett facilities. The validation has been carried out by the measurement of oil pressures and platform inclination. The Mean Absolute Percentage Error of the oil pressures determined by the model is 5.10%. This error is considered to be minimal therefore proving the concept and operation of the model and it is better than the variability of the experiments themselves. In summary, the model enables the fast and reliable determination of load stability allowing a variety of loading arrangements in a variety of highway conditions.

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APPENDIX A

The Problem is also the Solution: The Sustainability Paradox
Patricia Aloise-Young; Peter Young

Appreciating the Wicked Problem: A Systems Approach to Sustainable Cities
Barbara Colledge

Circular Economy Research in the Built Environment
Francesco Pomponi; Alice Moncaster

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Use of simulation through BIM-enabled Virtual Projects to enhance learning and soft employability skills in Architectural Technology education
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Naheed Khan; Muhammad Khalid Bashir; Darryl Newport

Procurement route and Building Information Modelling (BIM) implementation effect on sustainable Higher Education Refurbishment' projects
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Johann Meulemans; Florent Alzetto; David Farmer, Christopher Gorse

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Ahmad Al Kanani; Nashwan Dawood; Vladimir Vukovic

Fossil fuel reliant housing in Nigeria: physio-climatic regionalism as an energy/cost efficient perspective to providing thermal comfort
Alolote Amadi; Anthony Higham

Predicting future overheating in a Passivhaus dwelling using calibrated dynamic thermal simulation models
James Parker; Martin Fletcher; David Johnston

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Francesco Pomponi; Alice Moncaster

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Quintin Bradley

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Yahya Ibraheem; Poorang Piroozfar

Decarbonising construction using renewable photosynthetic materials.
Craig White

The Replacement of Wood or Concrete in Construction Projects – An Industrial Case Study Demonstrating the Benefits of Intrusion Moulded Mixed Waste Plastic
Paul Sapsford; Howard Waghorn

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