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Guest editorial

Revamping design, construction and operations for boosting built asset sustainability

With the construction industry inevitably being a major contributor to global greenhouse gas emissions, sustainability research has become a generic trend in the built environment. Once it has been decided to build a new building, or to refurbish an existing building, or change working practices, the opportunities for improvement through sustainable planning, design, construction, operations and maintenance practices are significant. To this end, sustainability solutions across a diverse range of projects in different contexts are required to bring change and innovations to the sector. However, there is still a lack of sustainability focus on the interfaces of design, construction and operational phases in construction projects that would eventually bring life to “Built asset sustainability”.

This Special Issue was aimed at revisiting and revamping traditional approaches to design, construction and operations with a common focus on boosting “Built asset sustainability”. There was an effort to connect processes and people engaged in different phases, where appropriate, to collectively and collaboratively address built asset sustainability.

This issue is lined up with the first five papers (Papers 1–5) suggesting the integration of different life cycles phases using technology (Paper 1 on blockchain technology), management theories (Paper 2 on lean principles) and sustainability frameworks/applications in unexplored contexts (Paper 3–5) to boost built asset sustainability. The last three papers (Papers 6–8) primarily focus on operational phase while attempting to link to either design or construction phases in varied contexts such as apparel (Paper 6), hotel (Paper 7) and university (Paper 8) sub-sectors. An overview of each paper is offered below.

The opening paper revolutionises the current state of sustainability thinking and integrates different stages of the life cycle of a built asset through blockchain technology. The authors, Alirez Shojaei, Jun Wang and Andriel Fenner, propose and test a model for using blockchain as an infrastructure support within a case study. The highlight of this model is its ability to offer a decentralised, transparent and comprehensive database for life cycle sustainability assessments. This is an evolving, but inspiring piece of research that opens up many avenues for future research in sustainability.

The second paper by Sonali Pandithawatta, Nisa Zainudeen and Savindi Perera, extends traditional lean construction applications based on economic considerations to “social and environmental” considerations in an attempt to boost built asset sustainability across its life cycle phases. This research is conducted in Sri Lanka through a qualitative research method incorporating expert interviews. The paper offers a framework to guide the implementation of integrated lean–green application in the studied context.

The third paper by Chukwuka Ohueri, Wallace Enegbuma and Hadina Habil attempts to apply a sustainability framework to office buildings in Malaysia, in particular testing of latest Malaysian Carbon Reduction and Environmental Sustainability Tool in office building contexts in Sarawak. The research findings are based on a survey of a pool of green construction professionals. The interesting outcome of this research paper is the holistic framework offered by the researchers by embedding existing local and global sustainability frameworks with four strategies on government policies and incentives coupled with technology and processes to integrate design, construction, and operation and maintenance phases and, thereby, to reduce carbon footprint and to promote built asset sustainability.

The fourth paper explores the adoption of renewable energy sources in commercial buildings in Nigeria by incorporating many stakeholder perspectives. The authors,
Maria Unuigbe, Sam Zulu and David Johnston, utilise a grounded theory method and identify five interesting themes as key factors in renewable energy adoption, namely being compliant, change in mindset, normalising, being autonomous and identity. The research method used to capture the perceptions of different stakeholders and the five themes/factors are worthy contributions of this research that would inform any sustainability adoption or application in built assets, in particular in developing countries.

The fifth paper by Subaskar Charles, Hearth Vidyaratne and Damithri Melagoda offers another sustainability application by attempting to integrate design and construction phases by exploring the adoption of green roofs for high-rise buildings in developing countries such as Sri Lanka. It is based on expert interviews and a questionnaire survey. The paper contributes to knowledge by identifying the most significant prospects over restraints that need extensive promotional strategies to motivate the adoption of green roofs in high-rise buildings. Apart from awareness and training, the paper imposes proper government regulations and policies, incentives and promotion as important strategies, in order to discuss green roofs in the upcoming high-rise building projects in Sri Lanka. It also provides the links of green roofs with the other facets of built environment sustainability.

The sixth paper by Nimesha Jayasena, Harshini Mallawaarachchi and Lalith De Silva is primarily focused on the operation phase of a built asset sustainability in the apparel sector in Sri Lanka. The paper provides useful insight into facilities management (FM) functions and indicators of environmental sustainability. The main empirical data collection tool was a questionnaire survey, while analytical hierarchy process was used to analyse data. The paper finds energy management to be the most significant FM function in terms of achieving environmental sustainability in the apparel industry, whereas water management, maintenance management, waste management and asset management were identified, respectively, as other key functions of FM. Ultimately, the paper develops and validates a framework that can be used as a firm base to assess the current status and to formulate the strategies for improving environmental sustainability in broader terms and assuring built asset sustainability.

The seventh paper by Fasna Fasly and Sachie Gunatilake attempts to link operational and construction phases through the adoption and implementation of Building Energy Efficiency Retrofits. It is based on two in-depth case studies in the hotel industry. The paper identifies 38 barriers, which had significant impacts during pre-retrofit, implementation and post-retrofit phases under the sub-groups of financial, technical, informational, managerial, institutional, behavioural, market and social barriers. Furthermore, the study identifies 77 strategies classified at individual, organisational and national levels to overcome the identified barriers. These strategies provide a basis for setting up country-wide and organisation-wide strategies for successfully improving the energy efficiency when retrofitting existing buildings.

Finally, the eighth paper by Joseph Adeleji, Joseph Fadamiro and Timothy Odeyale offers a feedback loop from operational phase to design phase through adapting post-occupancy evaluation of the University Campus Open Spaces (UCOS) in south-west Nigeria. It is based on a structured questionnaire through stratified random sampling. The findings indicate that males use the UCOS more for active and passive recreation than females, who are more concerned about safety and inclement weather. The results were synthesised into a framework, which guide future design actions for innovative strategies between design and use/operational phases to boost and optimise the life cycle sustainability of campus built assets.

In summary, the papers have identified the imperatives to integrate design, delivery and operational phases of varied construction projects to benefit from the true and full value of sustainability in construction projects. It is anticipated that the gaps and barriers addressed by the research papers in this Special Issue will eventually assist the construction industry in the continuing journey towards whole life cycle built asset sustainability. The research findings are expected to collectively inform relevant policy makers to develop guidelines
and good practices locally and globally. As a whole, the society would benefit from such sustainable and environmentally friendly practices and assist in achieving the global zero carbon targets.

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Exploring the feasibility of blockchain technology as an infrastructure for improving built asset sustainability

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Abstract

Purpose – The purpose of this paper is to show the feasibility of blockchain technology to perform as an infrastructure for improving built asset sustainability by providing all the necessary information for better decision making at all the stages of its life cycle.

Design/methodology/approach – Blockchain technology can be used as a tool to build a reliable and secure decentralized information system to capture and disseminate all the data required for different sustainability assessment models. A model is designed and tested through a synthetic scenario to substantiate the research objective with empirical work.

Findings – It is shown that blockchain can revolutionize the current state of knowledge for long-term sustainability thinking and provide necessary information in different stages of the life cycle of a built asset. With the proposed decentralized, transparent and comprehensive database using blockchain, the life cycle assessment methods can become much more inclusive and reliable. The new holistic analysis of the built asset sustainability enables better decision making in design, build, operation and demolition of each asset.

Originality/value – This paper proposes and tests a model for using blockchain as an infrastructure to support built asset sustainability. Practitioners from different backgrounds at different stages of a built asset life cycle can use such a network to make better decisions and better assess the sustainability of their built assets.

Keywords Sustainability, Assessment, Information systems, Decision support, Blockchain, Built asset sustainability

Paper type Research paper

Introduction

The architecture, engineering and construction (AEC) industry plays a significant role in environmental sustainability and directly contributes to the state of built asset sustainability. However, the AEC is an utterly fragmented industry where most of the firms are small–medium size, and the lack of coherence and proper communication has reduced its productivity and impacted the built asset sustainability severely. Typically, each stakeholder operates in isolation and hand over their product to the next stakeholder in the production line. Innovative solutions such as integrated project delivery and Building Information Modeling (BIM) have been introduced to remedy these issues. However, the current state of the built environment shows that although these solutions have been helpful, there are multiples problems unaddressed. One of the main issues plaguing the built environment is the lack of comprehensive information regarding each product and the
supply chain that procure that product. Different life cycle assessment (LCA) models have been tested to shed light on the assessment of life cycle cost, life cycle carbon and energy footprint. However, most of these models use limited databases regarding the number of products and even the information regarding each product is not necessarily comprehensive. Also, the supply chain route, the origin of products and respective raw materials and the final destination of the product and its respective distance from the source are not clear in most cases. This lack of information truly hinders the practice of conscious design where designers can choose the products in their design by considering its whole life cycle and its impact on the built environment sustainability. The same issue applies to contractors when they are purchasing materials such as cement, brick, metals, wood, among others. The total embodied carbon and energy footprint of a built asset is not only the direct carbon and energy incorporated in the asset but also includes all the carbon and energy that has been released/used for each incorporated product in the built asset from its raw material source to the manufacturing. This level of detail and information is, in most cases, not currently available in a transparent and modern way. Even the whole life cycle modeling attempts are not comprehensive enough for each product and only cover a limited set of products. Therefore, this paper discusses the viability of blockchain technology as an infrastructure for improving built asset sustainability through a comprehensive and detailed material traceability method.

This paper is organized as follows. First, the current state of the art in built asset sustainability is reviewed with a focus on LCA models. Afterward, the blockchain technology is introduced, its applications in the built environment are discussed, and the new generations of blockchain and their implications are reviewed. Next, a model for using blockchain to store and share the information in a cradle-to-cradle manner, which could potentially include the real energy and carbon footprint of each product is presented, discussed and tested through a case study. Finally, the paper concludes with summarizing its findings and directions for future research.

State of the art of the built asset sustainability

The built asset is defined as a man-made building or infrastructure subject to construction or where the construction asset can be stored in a digital format (BSI, 2015). The construction of an asset is based on an industry where project preferences and requirements constantly change, creating unique supply chains that are usually reorganized for each project. These unique characteristics of the construction industry create short-term relationships among stakeholders, poor information and data exchange, and lack of motivation for common learning (Hultgren and Pajala, 2018). Additionally, the same sector has historically suffered from the industry fragmentation, complex contractual agreements that often lead to change orders and disputes, resistance for innovative and disruptive solutions, and has one of the lowest levels of digitalization among the several industries (Barbosa et al., 2017). At the same time, the physical built asset has long been recognized by its significant impacts on the environment, which are worsened by the above-mentioned problems of the industry (Kibert, 2016).

Currently, one of the most important questions faced by construction professionals is how to make better and more sustainable decisions. Multiple sustainability assessment methods have been developed to gather and report project information systematically and holistically, facilitating decision-making processes. LCA has become the primary method for assessing the environmental impacts of the built asset or its components (Soust-Verdaguer et al., 2017). However, the large amount of information, synergies and trade-offs flowing through the product life cycle stages makes LCA analysis of a built asset a complex task. It has also been suggested that the LCA could not be used for the built asset sustainability in the same way as in other sectors because of the large amount of information associated with
the built asset (Gantner et al., 2015). Therefore, different types of LCA were developed, including basic calculations, which usually are conducted in Excel and include input and output data of a few impact factors; simplified assessment, which uses specific tools for the sector such as Athena, Ecosoft, and Equer; and detailed or advanced assessment, which requires higher level of knowledge and experience in LCA and uses Simapro, Gabi or Umberto software (Gantner et al., 2015; Kosanović et al., 2018). Although there has been an increased effort in collecting data from manufacturers and making it accessible to stakeholders through product datasheets, product specification lists, and environmental product declarations (EPDs), the lack of transparency of the sustainable parameters of a product and the uncertainties in the databases are still a major concern for the industry (Kosanović et al., 2018).

Software programs and databases are helping in calculating the input/output flows and sustainable parameters of the built asset. Software programs usually use information stored in databases most often provided by manufacturers (Kosanović et al., 2018). Significant research has also been conducted on integrating the BIM software programs, LCA methodology and optimization techniques for decision making at the early stages of the design (Wang et al., 2005). BIM is perhaps the most promising information technology that could be used to improve the built asset sustainability and asset management in the life cycle of a project as it enables collaborations among stakeholders while integrating several facets of the design process (Kivits and Furneaux, 2013). Thus, BIM-LCA has become a method to simplify the process of compiling life cycle environmental impacts of a project while helping in the decision-making process. However, studies have shown that using different LCA tools could result in significant differences concerning environmental impacts (Bueno and Fabricio, 2018; Soust-Verdaguer et al., 2017). Thus, transparency of data, reliability and validity are essential to reduce information uncertainty and improve eco-design through LCA tools.

Without a comprehensive system that collects and transparently stores information, the LCA tools somehow lack reliability and struggle to become broadly used in the industry. Therefore, the construction industry is struggling to make significant progress toward the broad scope of sustainability given the increasing need for efficient use of resources combined with the high complexity of projects and constant demand for high quality and cost control. One way to solve these issues would be through the implementation of digital and disruptive technologies such as blockchain technology, which has shown to improve the supply chain of other industries (Abeyratne and Monfared, 2016), the overall sustainability (Kouhizadeh and Sarkis, 2018) and has potential for the AEC industry (Shojaei, 2019).

Blockchain technology

Bitcoin, introduced by Satoshi Nakamoto in 2008, is considered as one of the most successful cryptographic currencies to date. Blockchain, the first distributed ledger technology, is the underlying technology and backbone of Bitcoin and other cryptocurrencies (Li et al., 2018). A blockchain is a chain of blocks of information that registers transactions, while a peer-to-peer (P2P) network of nodes is used to verify each transaction. Once a transaction is verified by the network, it is added to the blockchain and cannot be altered or tampered with. An overall working procedure of a blockchain is illustrated in Figure 1, including a transaction is requested; a block is created and represents the transaction; the block is broadcast to the P2P network; the network validates the transaction; the verified block is added to the blockchain; and the transaction is complete. In some case, multiple transactions can be presented in a single block. Each block generally has several pieces of information, including main data (depending on the blockchain application), the hash of the previous block, hash of the current block, timestamp, and other information (Lin and Liao, 2017). The hash value is a key element of each transaction and is used as the transaction
identifier (TXID). A newly verified block with its singular hash value will be put on the blockchain to form a unified distributed ledger (Kaushik et al., 2017). Several hashing algorithms are available for hash value calculation, and a good hashing algorithm has several requirements such as the output length and computation efforts. Hashing determines the level of security for the blockchain (Kaushik et al., 2017).

In essence, the blockchain technology is used for maintaining and verifying the integrity of the desired data. From the design perspective, blockchain technology is different from the traditional databases as blockchain is a decentralized technology that offers multiple advantages over conventional ones. The P2P framework adopted in the blockchain stores the data in all the nodes and ensures all copies of the records are identical with no conflicts. The data stored in the blockchain are not centralized, and as a result a central trusted authority is not needed to manage the data and ensure its integrity (Turk and Klinic, 2017). Each transaction, which has a unique TXID and a timestamp in a ledger, is authenticated and protected with different types of cryptography including cryptographic public and private keys. The decentralized aspect enables blockchain to be extraordinarily resistant to tampering, corruption and censorship (Peck, 2017). Therefore, the blockchain technology also is defined as “a programmable distributed trust infrastructure” (Turk and Klinic, 2017).

In a blockchain network, as explained above, a consensus algorithm is needed for transaction validation among the peers. A variety of algorithms are available to reach a consensus and ensure that a block is fully validated and is secured in a blockchain. A good consensus algorithm means efficiency, convenience, and security. In recent years, increasing endeavors have been made to improve consensus algorithms in blockchain (Zheng et al., 2017). Several consensus algorithms, including proof of work, proof of stake, practical Byzantine fault tolerance, delegated proof of stake, Ripple, and Tendermint exist (Zheng et al., 2017). In a blockchain, “mining” is the process of generating proofs so that a new block can be added to the blockchain. Thus, miners that conduct the validation of transactions are a core component of a blockchain network (Kaushik et al., 2017).

In addition to the vital applications in cryptocurrency (i.e. Blockchain 1.0), the blockchain technology has presented essential promises and evolved to be used in other disciplines such as smart contracts, i.e. Blockchain 2.0, and health, science, government, culture, and others, i.e. Blockchain 3.0 (Shojaei, 2019). However, as an emerging technology, blockchain...
also is facing multiple challenges and problems. Blockchain is identified as an energy-intensive technology with high power consumption (Gatteschi et al., 2018). The power consumption of each bitcoin transaction is estimated to be equivalent of 80,000 times the power consumption of a credit card transaction processing (Puthal et al., 2018). Another essential challenge is its scalability. High storage and processing power are required in a public blockchain as all of the transactions ever happened are required to be presented for validation of a new block. However, permission-based and consortium blockchains such as Hyperledger Fabric do not impose such a burden on the network as they are more efficient and have a better scalability.

Blockchain technology applications in the built environment

The studies of blockchain technology applications in the built environment are still at the infant stage, and the published literature is very limited. In a very recent work of Li et al. (2018), a systematic review of blockchain applications in the built environment was conducted and a total 53 papers were finalized, selected and reviewed. The extracted blockchain applications were grouped into seven categories, i.e. smart energy, smart cities and the sharing economy, smart government, smart home, intelligent transport, BIM and construction management and business models and organizational structures. The review showed that relatively more research has been performed on applying blockchain technology in the energy sector (the number of publications was considerably higher than that in other categories). The BIM and construction management was the second-largest category with nine publications, has proposed to use the blockchain technology to manage construction value delivery, productivity, collaboration and other aspects.

The application of blockchain in the built environment can offer numerous opportunities (Nawari and Ravindran, 2019; Shojaei, 2019). Mondragon et al. (2018) stated that blockchain could be useful for industries with stringent standards which require a proof history of material manufacturing, transportation, handling, and storage. In addition, blockchain can keep information on product manufacturing certifications, quality of products, and the true origin of resources. Also, the decentralization blockchain system discards the possibility of a single-point failure in the network while ensures the completeness of the information (Mondragon et al., 2018). Lastly, studies have shown the application of blockchain for procurement purposes, including the ability to make records available to interested parties and enabling audits on quality issues (Wang et al., 2017).

Development of a sustainable built environment requires interdisciplinary collaboration to consider the variety of social, economic and environmental impacts in the long term. A blockchain-based P2P energy transaction platform was proposed to promote a sustainable electrical energy transaction ecosystem between prosumers and consumers (Park et al., 2018). The decentralize feature of blockchain was also utilized for trading local energy generation and developing sustainable local energy markets (Mengelkamp et al., 2018). The results indicated that the blockchain technology offered several advantages such as cost-efficient microtransactions for local energy markets, but also had some limitations such as scalability issues. Mylrea and Gourisetti (2017) used blockchain to enhance smart grid resiliency by increasing the security and sustainability of the distributed energy resource integration. The results showed that utilizing blockchain could enhance the fidelity and security of buildings in grid communications. Luo et al. (2019) have proposed a semi-automatic smart contract framework for construction payments based on a blockchain network. The proposed framework can increase the efficiency and speed of construction projects.

Johansson and Nilsson (2018) mainly focused on investigating whether and how the blockchain technology could enhance sustainability for construction contractors. The authors showed that blockchain technology can prevent or mitigate five out of the seven identified sustainability scopes (i.e. material waste, non-sustainable materials, undeclared
work, repetitive strain injuries, accidents, employee payment and limited contractor base). The authors showed that the use of sustainable materials could greatly be improved due to the traceability, immutability, and transparency of the data. On the other hand, it was not considered as a potential solution for material waste and repetitive strain as those issues are mostly due to the processes itself. However, as noted by Kouhizadeh and Sarkis (2018), smart contracts could be used to restrict material waste and control hazardous waste. Thus, blockchain shows promising contributions to the sustainability of the built environment. However, further research is needed to fully realize its potential.

Overall, blockchain technology has been shown capable of improving built environment sustainability in four main areas (Chapron, 2017): ownership: blockchain can certify the existence of ownership; traceability: the input/output of resources and the ecological footprint can be tagged into the blockchain through sensors connected to the Internet of Things during the manufacturing processes of each material; incentives: the overall environmental impact can be recorded and sustainable behavior of a company can be rewarded through incentives or tax rebates (Truby, 2018); policy-making: the transparency of information helps stakeholders make better decisions and also helps the social sustainability by easily exposing frauds or illegal actions in the supply chain (Presley and Meade, 2010).

Research needs and objectives
The decentralized nature of the AEC industry and built asset production and maintenance have proved to be challenging regarding data collection and understanding of the whole life cycle impact that each built asset truly imposes on the planet. Blockchain provides a secure and reliable decentralized information system that could well address issues which arise from the inherent characteristics of the AEC industry. The objective of this research endeavor is to conceptualize and ultimately build the infrastructure to provide all the necessary information for better decision making for built asset sustainability at all the stages of its life cycle. This infrastructure should be able to collect, validate and store the data systematically, and the collected data should not disappear, or can be tampered with. The proposed framework, in contrast to the current argument that the built environment sector cannot use LCA in the same way as in other sectors because of the large amount of information that the built asset is composed of (Gantner et al., 2015), could be the infrastructure that enables collecting, storing and disseminating a large and decentralized database in a secure and reliable manner. The proposed infrastructure would minimize uncertainties and maximize transparency regarding the impact of user decisions. Also, the verification process would minimize existing trust issues in the industry. As mentioned in the previous section, framework and boundary conditions are essential for an LCA analysis. Therefore, with a decentralized, transparent and comprehensive database using blockchain, the LCA methods can become much more inclusive and reliable. Also, the users can get information regarding each specific product, instead of an average on the category. Ultimately, the new holistic analysis of the built asset sustainability enables better decision making in design, build, operation and demolition of each asset.

Blockchain as an infrastructure for sustainability
The decentralized, secure and reliable information system provided by blockchain can very well adopt to the fragmented and complex construction supply chain. The blockchain network illustrated in Figure 2 shows the flow of information conceptualized in this study. The first block of information is created when a raw resource is harvested. The first block contains the location, the energy that is used to harvest the material, carbon footprint, and the amount and characteristics of the raw material. Through Blockchain, each party is able to report the inputs/outputs based on a standardized metric, so that potential buyers from
Figure 2. The flow of information in the proposed blockchain network.

Building A

- Product A-1 (energy, carbon, raw material, and other characteristics)
- Raw material 1

Building B

- Product B-1 (energy, carbon, raw material, and other characteristics)
- Raw material 1

Product A-2 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 3

Product A-3 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 2

Product A-4 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 3

Product A-5 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 3

Product B-2 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 2

Product B-3 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 3

Product B-4 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 3

Product B-5 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 3

Product B-5 (energy, carbon, raw material, and other characteristics)
- Raw material transaction
- Raw material 3
all industries can evaluate all different raw materials and make their purchase based on their own decision-making criteria. The purchase is the second block of information, which includes the amount of raw material that is purchased in each transaction, by who and subsequently, the distance that the material is transported. All transactions can be performed through smart contracts and be accessible to all parties. Manufacturers can use the purchased resources to produce goods and products.

The next block of information is created where the amount and characteristics of each product along with the energy and carbon footprint of the production cycle is stored. This cycle might happen multiple times for certain products as manufacturers located on high stages of the production pyramid use the outputs of lower-end manufacturers. Eventually, the final products get to the vendors. This chain of information is available to architects and other potential clients and stakeholders. They can trace each product to its source and the embedded energy and carbon footprint of each product. They can also use LCA methodologies to assess the impact of their choices on the sustainability of the built asset and its impact on the environment. At this point, the blockchain has provided material transparency and carbon and energy footprint. This chain of information cannot be altered and the information it provides is going to be reliable. The chain of information continues, and new blocks are created as the product is purchased and incorporated in the built asset.

The owner/operator of the built asset can use the chain of information and get necessary details regarding each product, such as its source, material characteristics, maintenance instructions, among other specific details. The information regarding the performance of the products from the operation and maintenance of the built asset would configure the next blocks of information. At this point, any new decision cannot only go back in the chain and look to the source of each product but also consider future scenarios and performance of the product/material under examination. By connecting different management software, such as ERP and Scada, data across the several phases of the project can be simplified and organized in a comprehensive way. Transparency is improved as activities/processes use sensors connected to the Internet of Things to collect and store inputs/outputs.

Research method and the blockchain network framework
In this and the following sections, a blockchain network is designed and tested through a synthetic case study by matching the identified gaps in the built asset sustainability based on the reviewed literature and the advantages of blockchain technology. First, details of the proposed blockchain framework with the rationale for its design is discussed and then, through a synthetic case study, its feasibility is tested. There are different types of blockchain network based on their features regarding the level of decentralization, scalability and security. Each decision regarding each of the mentioned features would impact the other ones. In this study, a consortium blockchain as in a permission-based blockchain network format is developed and deployed using Hyperledger fabric to show the feasibility of blockchain technology as an infrastructure for improving built asset sustainability. In this type of blockchain network, a selected set of nodes make the consensus determination, the efficiency and scalability of the network are higher than the public ones. Although, the tradeoff is a lower level of security compared to a completely public blockchain such as Bitcoin. The decision of using such a network format is based on the fact that the participants involved in design, construction and operation of the built environment are a subset of the public. As a result, a more efficient network that can also accommodate the scale of the operation is more suitable.

The first step is to generate a business network based on a pre-defined model using the Hyperledger composer. Three main characteristics of the network that needed to be defined are the network model, business logic, and access control limitation. Network model contains the definitions of the main elements in the network such as assets, participants,
transactions, and events. Business logic covers the functions behind the transactions and what each transaction implements, and how it happens. Access control limitations regulate the capabilities of each participant in the network. In this study, three types of participants are defined, namely, manufacturer, trader and regulator. The relationship between the participants in the developed network is shown in Figure 3. Manufacturers are the producers of energy, Tier 1 and Tier 2 resources. Traders are the entities that can buy and sell resources but not create them. The regulator is the entity which oversees the transactions and issues the certificates for new participants to join the network. New participants based on their certificate (manufacturer or trader) can request/issue transactions observing the access control limitations which will be discussed later. Four types of assets are being defined, namely, energy, Tier 1 resource, Tier 2 resource and built asset. Tier 1 resource includes raw resources, and Tier 2 resource includes any processed material, and product. In other words, when a raw material is extracted, it is considered a Tier 1 resource and as soon as it goes through the first round of processing it becomes a Tier 2 resource. It will remain a Tier 2 resource no matter how much processing and combination with other resources happens to it until it will be used in a built asset. For each asset, a unique ID is assigned when they are created, and it will be identified through that ID in the network. Other features defined for each asset are name, description, resource type, balance (amount available), carbon footprint, manufacturer and owner. When the resource is produced the owner is its manufacturer, but after a purchase transaction, the owner changes and the balance would be updated. Seven types of transactions are defined as follow:

1. energy production;
2. energy purchase;
3. Tier 1 resource production;
4. Tier 1 resource purchase;
5. Tier 2 resource production;
6. Tier 2 resource purchase; and
7. built asset production

Accordingly, seven types of events are defined, where one relates to each transaction. These events will be triggered when a transaction is being confirmed, which will in return emit a

![Figure 3. The relationship between the participants](image)
notification to all the nodes in the network that a specific transaction is being confirmed. The access control limitation rules governing the network are as follow: manufacturers can request and read both production and purchase transaction; traders can only request a purchase of a resource and a built asset production transaction, but they can read all the production transactions, which would enable them to learn about available resources and their characteristics. The network is decentralized as the transactions are emitted to all the participants and everyone in the network has access to them. However, the certificate-based participation in initiating a transaction and the access limitations in the network defined ensures a clean and efficient network operation.

The last part of the blockchain model is the business logic which pertains the logic behind each transaction. The functions behind each production transaction are defined in a way to first check whether that user has the permission to produce that type of material or not. Then, the information provided by the manufacturer would be sent to the regulator as a transaction that would require approval. Upon the regulatory approval, the according event would be triggered, and all the nodes would be notified of the new transaction. The resource purchase transaction logic first checks whether there is enough requested resource available and upon approval of the seller, the transaction request would be sent to the regulator for approval.

Case study
A synthetic scenario for using gypsum panels in a building, from energy and raw resource production to its final use in a building, is simulated to verify the viability of the defined blockchain network using the Hyperledger Fabric platform. Figure 4 shows the network of all the participants with their unique IDs (left) and the proof of their existence in the network from the Hyperledger Fabric Graphical User Interface (GUI) (right). Six manufacturers are added to the network, one gypsum panel manufacturer, one glass matt manufacturer, one soda ash manufacturer, one gypsum extraction company, one sand and limestone extraction company and one energy manufacturer that produces two types of energy, one from renewable and one from non-renewable sources (coal in this case). The membership and privileges of each participant in the network are controlled by their certificate based on the access control limitations. The nodes, their certificates, and membership management system was implemented according to the detailed network description in the previous section (Figure 3 description).

Figure 5 shows the scenario that is used to test the network feasibility. The first row shows the raw materials extraction (natural gypsum ore, silica sand, limestone and soda ash) and energy production (Tier 1 resources) transactions. The second row shows the Tier 1 resource purchase transaction from the manufacturers. The third row shows the transactions regarding the production of glass mat, and gypsum panel using Tier 1 and Tier 2 resources, and energy. The last transactions are where the gypsum panels are purchased and installed in a building.

Each transaction represented in Figure 5 is added to the blockchain by a unique hash and timestamp after validation. Figure 6 presents the workflow of a sample transaction addition to the blockchain. Each participant can see the GUI (Step 1). After pushing the submit transaction button, the user arrives at Step 2 where they have to fill the required information for each transaction and send it to the network for validation. After validation, a unique asset with a unique asset ID is created (Step 3) and the transaction is added to the list of transactions (Step 4). The details of the transaction can be viewed and audited by the members of the network.

Discussion, limitations, and future directions
There is a significant difference in the environmental impacts that a material or a product imposes based on the source of energy that is consumed during its production. For instance, the significance of the production energy source on the supply chain can be seen when comparing the carbon footprint of a material produced with renewable production methods

Improving built asset sustainability using blockchain
Figure 4.
The network structure of the deployed blockchain and proof of their existence in the deployed network
such as solar panels with a material produced with electricity from the grid (usually coal). The current implementations of blockchain for energy management and distribution shows that blockchain is a viable solution for this sector (Mengelkamp et al., 2018; Park et al., 2018). Assuming that the energy market is going to drive on a blockchain network, the energy recordings discussed earlier in this section can indicate the actual source of energy at each step. This would allow a real-LCA where even the impact of the source of energy used in the production of goods and materials can be included in the assessments and the actual carbon footprint of a product and eventually, a built asset can be calculated.

In addition to a fully transparent and traceable track for materials and products, blockchain can also contribute to the idea of circular economy, prioritizing closed loops rather than the traditional linear processes. It also provides crucial information that can be used during decision making as a basis for planning for decommissioning a building and planning on reusing the materials in each building by better knowing their composition and characteristics. The blockchain framework proposed in this paper could become a backend infrastructure for different LCA methodologies as some stakeholders might not need to access the information chain directly, and only be interested in the final life cycle calculations. The proposed network could be incorporated into BIM and LCA software in a way that users can pull and push data from/to the network.

The proposed blockchain network would provide the users with full material traceability so they can make a more sustainable choice. The industry standard right now is that the supplier would provide the consumer with the required information. However, the reliability and accuracy of that information are always in question. The proposed network would provide the client with more reliable and accurate information and also access to more details regarding the source of the products, embedded carbon and energy footprint. One of the main advantages of such a network is that all the information is recorded in a verified, reliable, and organized way that front end systems can easily tap into the network and use.
Figure 6. The workflow of a sample transaction addition to the blockchain.
the data for each stage of the built asset life cycle. Another advantage of using a blockchain for material traceability is that a chain should be complete and verified in the network so products with incomplete and unverified entries would fail to be present in the market. The benefits of the blockchain infrastructure in the initial stages of the project is that the proposed structure could also help understand some important details that are currently unaddressed in the literature regarding the end-of-life of products/materials. Maintenance requirements can substantially be improved by analyzing the whole life cycle performance of the materials. Furthermore, recyclability could also be improved. Green building certifications can hugely benefit by having a reliable structure to verify the level of recyclable content in the building. In this study, the feasibility of blockchain technology as an infrastructure for built asset sustainability is examined, and a preliminary model is proposed and tested. The model structure, including the assets, participants, transactions, and events can be further improved from multiple aspects. Also, further research and improvement are needed to test the scalability, security, and efficiency of the model in real-world applications. Future research should focus on elaborating the model’s structure to suit the built environment better and eventually publicize a universal blockchain platform for sustainable material production and procurement that would enhance material traceability. Also, the integration of the proposed network with the current LCA frameworks and BIM would be a valuable contribution to the state of the knowledge and practice.

**Conclusion**

Reliable and accessible information management is the main challenge for sustainable assessment models such as life cycle cost and carbon analysis, whereas currently there is no coherent database containing all the necessary information regarding the supply chain of the products and their traces on the environment. The review of the literature shows that the current state of the built asset sustainability such as LCA methodologies lacks the thoroughness needed to achieve a cradle-to-cradle cycle and provide a comprehensive decision-making aid platform. In this paper, a blockchain information system is proposed to perform as an infrastructure to accurately evaluate built asset sustainability. To achieve the study objective, i.e., showing the feasibility of blockchain technology to perform as an infrastructure for improving built asset sustainability, some simplifying assumptions are made in development and deployment of the proposed blockchain network. The network itself can be a mean for verifying the information about a product. As the current source of energy of the manufacturer and its use are recorded on the system. The transactions of raw materials show where they are sourced from and how much raw material is being transferred in that transaction. This transparency forces everyone to perform with more caution regarding their actions impact on sustainability. Overall, the use of blockchain to collect, verify, store, and disseminate the data in each step from the raw material extraction to the operation of the built asset could potentially increase the built asset sustainability by providing transparent and comprehensive information to all the stakeholders involved in different stages of a built asset life cycle. The result of the case study shows that blockchain is a feasible technology to perform as an infrastructure for improving built asset sustainability and the proposed framework performs as expected.

**References**


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An integrated approach of Lean-Green construction: Sri Lankan perspective

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Abstract
Purpose – Construction industry hesitates to associate Green concepts on building projects mainly due to its high initial investment cost. Even if it is economical in the long run, often the benefits are suppressed with the costs generated through non-value-adding activities in the construction process. Lean construction principles have proved to eliminate such waste while enhancing the construction process. Thus, the purpose of this paper is to explore the applicability of the integration of Lean and Green concepts in the construction industry.

Design/methodology/approach – The fundamental principles of both Lean and Green construction were evaluated through an extensive literature survey. A qualitative approach was adopted, and thus, based on the literature findings, expert interviews were conducted with professionals having experience in both Green and Lean concepts. Furthermore, the findings were validated through experts to analyse the adaptability of the integration. Content analysis technique was utilised with NVivo software programme to analyse the findings.

Findings – The integration of the Green concept was found to alter the traditional application of Lean concept, considering the social and environmental aspects without limiting to economic considerations. The study revealed that the perception of the Sri Lankan stakeholders towards the application of integrated Lean-Green concept is focussed on a positive direction. As a result, the identified enablers to implementing the integrated concept supersede the barriers by confirming the appropriateness of the application in the local construction industry.

Originality/value – A framework was developed through the findings to guide the implementation of integrated Lean-Green application in Sri Lankan context.

Keywords Green construction, Lean construction, Flow activity elimination, Green concept, Integrated Lean-Green, Lean concept

Paper type Research paper

Introduction
The construction industry is one of the largest contributory sectors to the economies of many countries. At the same time, the industry significantly contributes to environmental degradation as one of the largest polluters (Alia et al., 2015). With the emerging recognition of adverse environmental impacts, the construction industry is pushed to take environmental considerations into the decision-making processes (Yates, 2007). Hence, the industry is continually being forced to minimise its large amount of energy consumption, and raw material and water usage (Low et al., 2012). Therefore, the construction industry has many opportunities in the enhancement of sustainable development to control the impact on the environment by integrating the Green concept into the construction plans (Hwang and Tan, 2012). For sustainable and Green growth, it is also essential to minimise the impact of construction activities on the environment. However, current construction methods are far from producing truly sustainable buildings (Nahmens and Ikuma, 2012). According to Ingle and Waghmare (2015), it is achievable via the proper implementation of Lean construction. Theoretically, Green construction focusses on reducing building energy use, water consumption, materials deployed and pollution (Abidin and Jaapar, 2008).

On the other hand, Lean construction emphasises on eliminating unnecessary activities while reducing waste in the processes used to design and construct buildings (Koskela, 1994). Although these two concepts have two different goals, evidently, both concepts
exhibit significant synergies on minimising the resource use (Jamil and Fathi, 2016). The journey towards greener operations and products have driven companies to search alternatives to balance efficiency gains and environmental friendliness in their operations and products, and the exploration of the sequential or parallel deployment of Lean and Green concepts is the result of this balancing act. Furthermore, the Lean concept’s alignment with the Green paradigm and its methods and tools seem natural as it aims at eliminating waste (Garza-Reyes, 2015).

Only a few researchers so far have explored the relationship between Lean and Green concepts (Dües et al., 2013). To date, no investigation has been done from the Sri Lankan construction industry perspective in this regard. Thus, it is a timely need to perform a comprehensive study on integrating Lean and Green concepts from Sri Lankan construction industry perspective to optimise the value generation. Ideally, the applicability of the integration of Lean and Green should be investigated on a life cycle basis since each stage of building life cycle raises questions of sustainability. However, this paper only focuses on the construction phase of the building life cycle, since one of the key focuses of Lean construction is waste elimination from the construction phase. Therefore, this paper aims to investigate the applicability of the integration of Lean and Green concepts during the construction phase through the perceptions of industry stakeholders. Also, the study intends to develop a framework on integrated Lean and Green concepts to Sri Lankan construction industry.

Theoretical perspective of Lean-Green integration

Green construction

Construction is a major industry throughout the world that primarily influences the environment, economic and social development (Chan et al., 2009). However, it also considerably contributes to numerous negative environmental impacts (Illankoon et al., 2017). According to Pink (2012), the construction industry is considered as one of the major industries which emit greenhouse gases extensively while contributing to about 26 per cent of waste. Furthermore, Pulselli et al. (2007) revealed that the construction industry exploits almost 40 per cent of the world’s consumption of materials. With the growing recognition of global climate change, there is a massive pressure on the construction industry to take environmental parameters into the daily decision-making processes (Peng and Pheng, 2011).

With the growing global interest in sustainability, Green construction is identified as a way for the construction industry to contribute to sustainable development, and thereby, to improve social, economic and environmental conditions of present and future generations (Abidin, 2010). Even though Green buildings deliver many benefits, there are several concerns connected with initiating Green building concept due to its high initial cost (Ahn and Pearce, 2007). Li et al. (2015) have identified Green construction as an integrated framework of design, constructions, operations, maintenance and demolition processes that consider environmental, social and economic effects of construction projects. However, as per Rosenbaum et al. (2012), sustainability research in construction has mostly focussed on the design and operation stages of projects, and the construction stage has not received much attention. During the construction phase, careful attention must be placed on both construction opportunities and design strategies to ensure that the project is delivered in a sustainable manner (Ahn et al., 2016), and a range of green technologies and strategies can be deployed throughout the construction phase for its achievement. For example, minimising site disturbance, erosion and sedimentation control, pre-construction services, pollution prevention, construction waste management, green materials management, sustainable site operations, indoor air quality management and commissioning could be identified (Ahn et al., 2016; Frattari et al., 2012).
Lean construction

The productivity of the construction industry has been declining worldwide over the past 40 years, and Lean construction can be implemented as an approach to overcome this situation (Aziz and Hafez, 2013). The Lean concept targets on eliminating all expenditures on resources which do not create value to the end customer (Čiarnienė and Vienažindienė, 2015). Non-value-adding activity elimination will reduce the costs and cycle time by increasing the customer responsiveness, the effectiveness and the competitiveness of the organisation (Alukal, 2003). The Lean concept categorises all activities of the system into two main categories, based on the added value on the end product or process. Thereby, the value-adding activities are recognised as “conversion activities”, while non-value-adding activities which consume resources and time are referred to as “flow activities” (Koskela, 1992). With the adoption of Lean construction, conversion activities are improved, and flow activities are eliminated (Peng and Pheng, 2011).

Koskela (1992) has ascertained eleven basic principles of Lean construction to be implemented in the construction industry, addressing the entire flow process and its sub-process. They are: reduce the share of non-value-adding activities; increase output value through systematic consideration of customer requirements; reduce variability; reduce the cycle time; simplify by minimising the number of steps, parts and linkages; increase output flexibility; increase process transparency; focus control on the complete process; build continuous improvement into the process; balance flow improvement with conversion improvement; and benchmark. It is noteworthy to identify that these principles are under the core principle of eliminating non-value-adding flow activities and increasing value-adding conversion activities. Thus, the adoption of the core principle supports the adoption of sub-principle without any extra effort.

Need for Lean and Green integration in the construction phase

Lean and Green construction practices are considered as two different independent strategies where the Lean process mainly aims at increasing economic standards, while Green predominantly aims at improving environmental objectives (Khalafan et al., 2001; Koranda et al., 2012). Many types of research have studied the impact of Lean concept to sustainability. These studies are critical to identify the basis behind the integration of Lean and Green concepts. As per the studies conducted by the US Environmental Protection Agency (2003) and Huovila and Koskela (1998), implementation of Lean strategies creates an atmosphere that is highly conducive to waste minimisation and pollution prevention, which contributes to the environmental dimension of sustainability. Moreover, Saurin et al. (2006) and Mitropoulos et al. (2007) found that Lean concept can have positive impacts on safety, which contributes to the social dimension of sustainability during the construction phase. Therefore, Nahmens and Ikuma (2012) suggested that implementing Lean construction offers the construction industry an approach to improve sustainability by optimising resource utilisation and human safety during construction activities and minimising waste through standard procedures.

Conversely, the relationship between Lean and Green has several contradictions (Garza-Reyes, 2015). For example, when Lean provides solutions for cost efficiency and quality, it can create more harm to the environment (Rothenberg et al., 2009). This is mainly due to lesser focus on social and environmental components in the Lean concept (Kleindorfer et al., 2005). The emphasis of Lean concept to maximise value for the customer can dilute the environment and social considerations (Bae and Kim, 2008).

While analysing the above literature findings, the main focus of Lean is not necessarily of minimising environmental impacts, since the primary purpose of Lean is to provide excellent value to the client while maximising profits through cost reduction (Bae and Kim, 2008; Carvalho and Cruz-Machado, 2009). By introducing social and
environmental issues as new values, Lean construction will assure positive environmental and social effects (Bae and Kim, 2008).

The literature synthesis identified that the Lean had some positive outcomes towards Green concept while also having some negative outcomes, as Lean philosophy mainly focusses towards output quality in terms of customer requirements. On the other hand, Green concept has some attributes that negatively impact on customer requirements while its positive attributes towards environmental and social benefits. While integrating the two concepts, they appear to be complementary to each other, by overcoming each other’s negative aspects, as denoted in Figure 1. Thus, the integrated practice can have a better outcome than them performing separately.

**Research methodology**

At the outset of the study, a literature review was conducted to identify the main features and principles of Lean and Green concepts, and to recognise the conceptual relationship between the concepts. A study conducted by Madushan et al. (2016) disclosed that 85 per cent of the construction industry professionals in Sri Lanka are not aware of the word “Lean Construction”. Moreover, the findings of Athapaththu et al. (2016) revealed that contracting organisations are at an initial stage of implementing sustainable practices, and unlikely in the global context, employees at all levels have no sufficient knowledge about Green construction. Therefore, a smaller number of experienced experts are available in Sri Lanka on the Lean and Green concepts.

The qualitative methods are identified as a robust approach in measuring descriptive aspects, and in the absence of numerical data, they help to deeply understand and interpret conditions (Bayraktaroglu et al., 2006). Moreover, qualitative techniques help to determine

**Figure 1.**

Basic platform to integrate Lean and Green concepts
more objectively the reliability and validity of subjective data (Amaratunga et al., 2002). By considering these facts, the qualitative approach was selected as the most appropriate, to achieve the aim of the study through opinions, experience and suggestions.

As a result, ten experts with more than 10 years of experience were interviewed from both contracting and consultancy organisations to obtain a broader range of data. Purposive sampling techniques were adopted due to a smaller number of available experienced experts in Sri Lanka about the Lean and Green concepts. The interviewees were selected from the top tier management as the integration needs to be initiated from the senior level of the organisation. Based on the literature findings, the interview guidelines were developed to identify integrated Lean-Green practices and enablers and barriers for their implementation. Table I presents the experiences and exposure of the interviewees related to Lean and Green concepts.

<table>
<thead>
<tr>
<th>Respondents</th>
<th>Designation</th>
<th>Experience (in years)</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Site engineer</td>
<td>Above 15</td>
<td>Worked at a project which won the Gold rated Green Award given by GBCSL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience in projects where Lean and Green concepts were implemented</td>
</tr>
<tr>
<td>R2</td>
<td>Planning engineer</td>
<td>Above 15</td>
<td>Participated in the Associate Professional Training Course conducted by GBCSL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Worked at a project which won the Gold rated Green Award given by GBCSL</td>
</tr>
<tr>
<td>R3</td>
<td>Managing engineer</td>
<td>Above 10</td>
<td>Experienced on implementing Lean concept in domestic projects</td>
</tr>
<tr>
<td>R4</td>
<td>Architect</td>
<td>Above 10</td>
<td>Participated in the Associate Professional Training Course conducted by GBCSL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience in projects where Lean and Green concepts were implemented</td>
</tr>
<tr>
<td>R5</td>
<td>Project manager</td>
<td>Above 15</td>
<td>Worked at a high rise Green building project in Sri Lanka</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience on implementing Lean and Green concepts in domestic projects and international projects</td>
</tr>
<tr>
<td>R6</td>
<td>Chief quantity surveyor</td>
<td>Above 10</td>
<td>Carried out a research study on Lean concept</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience in projects where Lean and Green concepts were implemented</td>
</tr>
<tr>
<td>R7</td>
<td>Project coordinator</td>
<td>Above 25</td>
<td>Performed as a civil engineer, quantity surveyor and facilities manager</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience on implementing Lean and Green concepts in domestic projects</td>
</tr>
<tr>
<td>R8</td>
<td>Project manager</td>
<td>Above 15</td>
<td>Worked at a Green university project which won the Building and Construction Authority (BCA) Green Mark Gold rating for sustainable buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience on implementing Lean and Green concepts in domestic projects and international projects</td>
</tr>
<tr>
<td>R9</td>
<td>Project manager</td>
<td>Above 20</td>
<td>Worked at a high rise mixed development project</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience on implementing Lean and Green concepts in domestic projects</td>
</tr>
<tr>
<td>R10</td>
<td>Architect</td>
<td>Above 15</td>
<td>Worked at a Green university project which won the Building and Construction Authority (BCA) Green Mark Gold rating for sustainable buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience in projects where Lean and Green concepts were implemented</td>
</tr>
</tbody>
</table>

Table I. Composition of respondents
Unstructured interviews were performed with open-ended questions to gather data. Data were analysed using code-based content analysis with NVivo 11 software. Based on the findings of the first round of expert interviews, the integrated Lean-Green framework was developed, which was subsequently validated through the same experts with modifications.

**Research findings**

*Current status of implementing Lean and Green concepts in the Sri Lankan construction industry*

All respondents agreed that the current implementation level of the Green concept and Lean concept is at a very low level in the Sri Lankan construction industry compared to the global context. However, R6 exposed that the implementation level has gained a significant improvement during the past decade, indicating a promising continuous growth in future. On the other hand, R2, R3, R5, R8 and R9 agreed that most Sri Lankan construction industry professionals do not know the concept of Lean as a theory; nevertheless, they implement most of the Lean techniques in the Sri Lankan construction industry.

Similarly, Thilakarathna and De Silva (2018) found that almost all the Lean techniques are implementing in the local industry at different levels, at 40 per cent of average. However, the respondents stated that not knowing the basic concept, theories and principles restrict the industry from achieving all the benefits the concept offers. Table II elaborates the identified reasons behind the low level of application of Lean and Green concepts and the respective respondents who suggested them.

The findings demonstrate that insufficient knowledge relating to the Lean concept is the main reason for its lack of application. Most of the other reasons, such as misconception, implementation issues, insufficient management support and resistance to change occur due to insufficient knowledge. Therefore, to improve the current Lean application level in Sri Lankan construction industry, this issue needs to be addressed immediately.

Considering the Green concept, lack of Green professionals is the most influencing factor for its low level of implementation. Since the Sri Lankan construction industry lacks Green materials and technologies, the initial cost of construction is high. According to R5, R8 and R9, Sri Lanka is rich with resources and knowledge sources that allow surveys in Green technology. Therefore, the government must take prompt actions to improve funding to make investigations to control this cost influence. Developer’s lack of knowledge concerning Green concept can be overcome with the consultant’s contribution. Anyhow, with a low level

<table>
<thead>
<tr>
<th>No.</th>
<th>Reason</th>
<th>Lean concept respondents suggest</th>
<th>Green concept respondents suggest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lack of knowledge</td>
<td>R2, R3, R4, R5, R6, R7, R8, R9, R10</td>
<td>R1, R2, R3, R5, R6, R7, R8, R9</td>
</tr>
<tr>
<td>2</td>
<td>Misconceptions</td>
<td>R1, R2, R3, R5, R7, R8, R9, R10</td>
<td>R2, R3, R4, R5, R7, R8, R9, R10</td>
</tr>
<tr>
<td>3</td>
<td>Lack of standard practice</td>
<td>R2, R3, R4, R5, R7, R8, R9, R10</td>
<td>R1, R3, R5, R8, R9, R10</td>
</tr>
<tr>
<td>4</td>
<td>Implementation issues</td>
<td>R1, R3, R4, R5, R7, R8, R9, R10</td>
<td>R1, R3, R5, R6, R8, R9, R10</td>
</tr>
<tr>
<td>5</td>
<td>Insufficient support from the top management level</td>
<td>R1, R2, R3, R4, R7, R8, R9, R10</td>
<td>R1, R2, R3, R5, R8</td>
</tr>
<tr>
<td>6</td>
<td>Employee resistance to change</td>
<td>R2, R4, R5, R6, R7, R10</td>
<td>R2, R3, R5, R7, R10</td>
</tr>
<tr>
<td>7</td>
<td>Hierarchical project organisational structure</td>
<td>R2, R3, R4, R7, R8, R9</td>
<td>R2, R3, R5, R7, R10</td>
</tr>
</tbody>
</table>

*Table II. Reasons for the low application level of Lean and Green concepts*
of Green professionals in Sri Lanka, it seems to be a challenging task to initiate. Therefore, increasing the number of Green professionals would be a pivotal point to increase the implementation of Green concept in the Sri Lankan construction industry.

Contribution of the Lean concept to Green construction
As per Athapaththu et al. (2016), Sri Lankan construction industry suffers from environmental, economic and social issues due to the unsustainable development activities that have been undertaking over the past decades. Therefore, a question was directed to the experts to express their opinions on the contribution of the Lean concept towards sustainability in the construction phase. Eight respondents out of ten exposed that, Lean minimises the material wastage as it eliminates non-value-adding activities in the building delivery process, which could otherwise contribute to environmental pollution. Furthermore, seven respondents specified that Lean helps to maintain the site in a clean and orderly manner which indirectly contributes to eliminating accidents on-site and thereby increases the social value of the project. Six respondents identified the improved ability to meet changing orders as a main contributory factor which helps to eliminate non-value-adding activities and wastes from the process. As per R5, Lean provides the platform to maintain the machines, tools and equipment in a way that improves its efficiency level. He further stated that these performance increments would result in economic benefits to the project. Agreeing with his decision, five respondents identified increased efficiency level of machines, tools and equipment as an advantage. Optimised energy used and reduced process variability that was identified by four respondents, highlighting their positive influence on the environment. The above-mentioned economic, social and environmental benefits prove that Lean implementation is capable of delivering Green impacts to a project by ensuring sustainable development in the industry. However, all the experts highlighted the importance of evaluating every Lean principle in terms of its impacts on the Green concept, conducted through the second section of the interview guideline.

Integrated Lean-Green approach
The initial set of questions in the second section was directed to identify the general practices under each Lean construction principle. However, the implementation of Lean construction principles under the Green concept requires the incorporation of social, economic and environmental aspects, changing its traditional application. Therefore, during the second set of questions, the interviewees were asked to reconsider all social, economic and environmental aspects regarding their applicability under proposed activities. As a result, some previously suggested activities under general practices were rejected, while some activities were modified as per the Green requirements. However, some activities remained unchanged since those activities do not have any negative impacts on the Green concept.

The research was then extended to recognise the relationship between Lean principles, when Green concept creates influences on them. It was identified that activities proposed under some principles have positive influences on the implementation of other principles. By considering these relationships, those principles were connected and narrowed down to six main principles, as demonstrated in Figure 2.

Koskela (1992) perceived that the ultimate goal of the Lean concept is the reduction of non-value-adding activities and improving conversion activities. Therefore, the framework mainly addresses the flow and conversion activities associated with the Lean-Green construction process in a way that it facilitates the Green concept. The relationship modelled considers the primary goal of each Green integrated Lean principle. Other relationships among those principles were neglected to sustain the simplicity of the model.
Combining “requirements consideration” and “variability reduction”
According to R10, the conventional method of identifying customer requirements is limited to considering the values expected by the developer. However, with the integration of the Green concept, the process becomes more complicated. Thus, the project team needs to identify the environmental and social values of the facility, along with the values expected from the developer. With the integration of the Green concept, three respondents out of the ten stated the importance of identifying social and environmental requirements to reduce the influence of variable factors of the project. Accordingly, identification of social and environmental requirements along with the customer requirements is a means to achieve variability reduction in the Green construction process. Therefore, “Requirements consideration” can be implemented under the principle of “Variability reduction”.

Combining “benchmarking” and “build continuous improvements”
As per R10, benchmarking helps to identify critical areas to be improved in the construction process, and R7 stated that implementing benchmarking along with Green concept is required to measure the environmental performance and compare it against industry competitors. As stated by R2, when the construction process is reviewed from the environmental aspects, it would bring a number of opportunities which will increase the efficiency by eliminating the risk of environmental impacts. Furthermore, seven out of ten respondents identified benchmarking to identify new Green technologies, materials and ideas, which can be used to improve the quality of the construction process.

According to R4, building continuous improvements under the Green concept require many studies, since each action needs to be evaluated from the economic, social and environmental aspects. Therefore, this necessitates to continuously study the industry leaders who adopt the Green concept successfully in the industry.

These findings substantiate that benchmarking helps to build continuous improvements in the construction process. Thus, benchmarking can be exercised under the principle of continuous build improvements. Therefore, the principle of “benchmarking” was included or integrated under the principle of “build continuous improvements”.

Figure 2. Relationships among Green Integrated Lean construction principles
Combining “balancing flow-conversion activities” and “cycle time reduction”

Keeping the right balance between eliminating flow activities and improving conversion activities is a valuable exercise to undertake. As per R9, the complete elimination of flow activities is an unachievable target. Therefore, attention should be placed on improving conversion activities. Furthermore, by expanding the argument, R4 stated that the elimination of avoidable flow activities needs to be emphasised than eliminating non-avoidable flow activities such as inspection. Hence, a clear idea about those two types of activities is necessary before implementing this principle. R3, using his management skills and experience related to the industry, explicated that, generally, the right balance of improving conversion activities and eliminating flow activities is decided based on the most economical solution. However, Green integration has led to consider the social and environmental aspects as well. This opinion demonstrates that the Green integration has implemented Lean principles into a new direction, where it takes social and environmental requirements as values to achieve.

On the other hand, all respondents stated that total cycle time reduction under Green concept intensified the necessity of considering the environmental and social aspects. As per R2, R3 and R9, satisfying economic, social and environmental aspects while reducing cycle time is required to maintain a better balance between flow elimination and conversion improvement. Therefore, the principle of “balancing flow improvement with conversion improvement” needs to be implemented along with the principle of “cycle time reduction” in order to achieve Greener results.

Combining “holistic controlling” and “increasing process transparency”

In the conventional approach, processes were separated into several parts and controlled under the supervision of multiple responsible parties. Out of ten, seven respondents identified the hierarchical project organisation structures as the reason behind this practice. The respondents suggested flat organisational structures as a solution to mitigate this issue. As per R1, adoption of flat project organisation structures reduces the multiple handling and error correction time by improving the information flow within the organisation structure.

With the Green concept integration, under the social aspect, the psychological safety of employees was considered. Six out of ten respondents exposed that employees in the traditional hierarchical project organisation structure are afraid of being punished or humiliated for questioning, sharing an idea, and for making mistakes. Moreover, these respondents suggested self-directed work teams as a sustainable option of controlling the complete process because it mitigates the above-mentioned negative influences on employees. According to R8, self-directed teams that are empowered to take decisions can improve the transparency of the project by bringing multiple advantages to the project management process. Yet, the groups’ composition must include the right mix of skills and be designed with freedom for group members to be responsible for an entire task.

As per these findings, it is apparent that the transparency of the construction process can be increased through a holistic controlling approach of the complete construction process by using self-directed teams and flat organisation structures to execute the construction work to increase the flow of information within the project and allow the reach of relevant information. Therefore, the principle of “holistic controlling” can be implemented under the principle of “increasing process transparency”.

Based on the above justifications and combinations, six main aspects of the Lean-Green construction process were identified. They are process variability, cycle time, transparency, simplicity, flexibility and continuous improvements. Giving prominence on such aspects would reduce flow activities and improve conversion activities within Green paradigms.
Integrated Lean-Green framework
The integrated Lean-Green framework is a summary of research findings. As discussed above, the implementation of Lean has indirect positive Green impacts, but it can also have negative impacts. If it is possible to set environmental and social issues as values to achieve at the beginning of Lean implementation, those issues can be addressed, and the Green products can be delivered effectively. The integrated Lean-Green framework was developed based on this phenomenon, where it will set the path to achieve a Green facility effectively by eliminating current pessimism as portrayed in Figure 3.

The integrated Lean-Green framework provides a platform to eliminate flow activities and improve conversion activities in a way that it would not be harmful to the Green concept. The six main aspects of the Lean-Green construction process, namely, process variability, cycle time, transparency, simplicity, flexibility and continuous improvements are addressed to make the process more productive and cost-effective. Giving prominence on those aspects would result in a reduction of flow activities and an improvement in conversion activities. The given activities, enablers and barriers are prioritised based on the response rate of the relevant activities and categorised into three main groups as “highly influential” if the response rate is more than 6/10, “moderately influential” if the response rate is more than 3/10 and “less influential” if the response rate is equal or less than 3/10.

Enablers and barriers in implementing Lean-Green application. The findings revealed some of the identified enablers prevalent in the Sri Lankan construction industry, which will support the implementation of Lean-Green application. Strengthening these enablers is critical in order to accelerate the implementation process.

The respondents identified the opportunities available to increase the knowledge level relating to Lean and Green as an accelerating factor for the application of an integrated framework. Continuous Professional Development (CPD) sessions on Lean and Green concepts, training workshops, education of Lean and Green concepts for the construction-related undergraduates, increased amount of research on these areas, and recently introduced university courses will eventually facilitate the application of the integrated concept effectively. Seven respondents out of ten explicated that the influences of the consultant can make a significant role in improving the quality of the project by introducing new concepts. R4 mentioned that the influences of the consultant could play a major role to upgrade the quality of the project by introducing new concepts. The government involvement in introducing new rules and regulations and steps to increase public awareness on Lean and Green concepts were also identified as accelerators which can positively influence the implementation of the integrated approach. The growing demand for Green facilities emphasised the need for an effective and efficient construction process, highlighting the importance of integrated Lean-Green application.

Retarders of the implementation process of the integrated approach are the amalgamation of the barriers in implementing individual concepts. However, it was also identified that the integration might lead to counteract each other’s barriers. For example, the high initial cost of Green concept implementation can economise with the integration of the Lean construction principles. As a result, only four respondents have identified the high initial cost of green construction as a barrier to the implementation of the integrated approach. As discussed in the literature, the Lean concept creates greater harm to the environment and increases the pressure on labourers when providing solutions for cost efficiency and quality because of the absence of ethical components. This is the main barrier to the Lean concept implementation. However, none of the respondents identified environmental issues as a barrier, and only three respondents identified increased pressure on labourers as a barrier to implement the integrated concept. This is because Green concept integration brings in the ethical component that is lacking in the Lean concept by creating
Figure 3: Integrated Lean-Green Framework

**Enablers**
- Conducting CPO sessions on integrated Lean-Green approach
- Efficient Green building delivery process
- Conducting training workshops
- Green construction award system and Green rating system for built environment
- Government new rules and regulations
- Consultant’s contribution to shape up client’s requirements
- Increased number of research studies relevant to these areas
- Growing demand for green facilities
- Educating Green and Lean concepts to construction related undergraduates
- Increase public awareness on Lean and Green approaches
- Increasing top management commitment
- Recently introduced university courses

**Barriers**
- Lack of professionals related to Lean and Green areas
- Lack of knowledge about integrated Lean Green approach
- Misconceptions
- Limited availability of Green materials and products
- Inadequate knowledge in relation to green technologies
- Lack of availability and reliability of Green suppliers and sub-contractors
- Lack of top management commitment
- Inadequate government commitment
- Employee resistance to change
- Unsupportive project organisational structures
- High initial cost of green construction
- Increased pressure on labourers for quality achievement
- Antinatal barriers

**Continuous improvements**
- Adopting new Green technologies
- Carry out regular maintenance for tools, equipment and machineries
- Set targets for every everyone working in the project including performance targets and Green targets
- Identify performance gaps in the current process in terms of exercising Green concept
- Study industry leaders who perform well and exercise Green concept well in the industry
- Implement benchmarking as structured and systematic process
- Establish rewarding systems for both technical and management staff and set workers’ adherence to the Green concept as an evaluation criterion
- Review the current industry practices and identify areas to improve
- Smoothen the information flow within the project organisation structure
- Measure and monitor the improvements regularly
- Carry out team building workshops
- Mutually exchange beneficial information with competitors

**Simplicity**
- Integrate the contractor throughout the design phase
- Reduce flow activities by considering social and environmental aspects and eliminate these flow activities from the process
- Adopt a simple Green design
- Adopt Green standards

**Flexibility**
- Adopt “ET” approach in material purchasing by consider the carbon footprint on the environment during transportation
- Smoothen the information flow within the project organisation structure
- Increase the number of concurrent activities

**Variability**
- Identify social and environmental requirements along with customer requirements
- Profit maximisation
- Off-site manufacturing
- Sub-contract specific fields with contractors who adopt Green concept
- Use standardised Green buildings, Green designs, Green processes, Green materials and components
- Modularisation
- Better coordination with suppliers who adopts Green concept

**Transparency**
- Improve collaboration between stakeholders
- Conduct daily site meetings for labourers to educate environmental and safety aspects of their daily routines
- Build virtual mock-ups
- Display materials and tool handling process within the working environment by using oral communication and pictorial illustrations
- Use pictorial illustrations to display the steps of activities near the relevant working areas
- Display environmental and safety concerns within the premises
- Maintain the workplace in clean and orderly manner
- Integrate self-directed work teams to project management
- Display information in to the working environment
- Integrate self-directed teams to project management and empower the teams to make decisions
- Develop the self-directed team with the right mix of skills and include a Green expert in each team
- Using process maps

**Cycle time**
- Use quality Green materials
- Reduce organisation layers to empower the persons working directly within the flow
- Adopt better planning techniques to eliminate unnecessary waiting time
- Eliminate avoidable flow activities and improve conversion activities based on economic, environmental and social impacts of the activities
- Maintain machines and equipment to improve reliability and quality
- Identify all the conversion and flow activities in the construction process
- Separate all the unavoidable and avoidable flow activities
- Arrange the site layout in a way that moving distances are minimised
- Manage the site for improved environment performance
- Avoid unnecessary inspection
social and environmental concerns as values to achieve. Lack of professionals related to Lean and Green areas, lack of knowledge about the integrated approach and misconceptions were recognised by the majority of the respondents as barriers for the implementation of the integrated approach. Issues such as lack of top management commitment, employee resistance to change and unsupportive project organisation structures were identified by four to six respondents as weakening factors of the application process. R2, R8 and R9 expressed that the enablers available towards the implementation of the Lean-Green approach are much more powerful than the barriers that hinder the application of the integrated approach. It was further exposed that strengthening the available enablers that accelerate the implementation process will help to overcome those barriers by ensuring the successful execution of the Lean-Green approach.

Validation of the integrated Lean-Green framework
The proposed framework was validated by two experts who were randomly selected from the same expert panel with suggestions to improve and make modifications. The relationships established between Lean construction principles were confirmed by the interviewees highlighting the fact that all Lean construction principles contribute to reduce flow activities and improve conversion activities which are the core idea of the Lean concept. The interviewees agreed with the idea of linking Green integrated Lean construction principles by perceiving that the activities involved with some of the principles can directly influence the implementation of other principles. With the possible favourable outcomes of the framework, it was suggested that the available barriers could be overcome, and thereby it is possible and beneficial to implement this framework in the Sri Lankan construction industry. It was further added that a shift towards modern procurement systems is encouraged by the contractor engaging in the project from the early stages, which could bring further efficiency in implementing the concept. Process improvement, waste elimination, reducing cycle time, avoiding rework, reducing design changes, better technological solutions on construction methods, material choices and a workable project programme are some advantages identified. It was also noted that such procurement systems could bring benefits against the traditional procurement process, where inefficiencies are laden in the project in various aspects that finally may result in failure of achieving project goals; i.e., time, cost and quality targets.

Conclusions
Lean and Green concepts have distinct features, aiming at enhancing diverse attributes of a construction project. However, both the concepts focus on refining the project performance irrespective of the aspects on which they are concentrated. The literature findings exposed that the issue of high initial cost associated with Green can be addressed with Lean, while social and environmental issues connected with Lean can be addressed with Green, providing a platform for integration. Hence, the findings of the research substantiated the need for Lean-Green integration. Furthermore, the Sri Lankan construction stakeholders have acknowledged the contribution of the Lean concept to Green construction, which is the key governing factor to decide their perception in relation to the applicability of the integration of Lean and Green in the Sri Lankan construction industry. The framework developed for the implementation of integrated Lean-Green concept was validated through expert interviews to analyse the suitability of the study, and the number of interviews was limited only to two due to time constraints available to the research. The scope of this research was limited to the construction phase. Therefore, the integrated Lean-Green framework will allow to adopt a consistent and productive construction process. The implementation of the framework will be associated with numerous enablers and barriers where the barriers can be mitigated through strengthening the enablers.
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Further reading

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MyCREST embedded framework for enhancing the adoption of green office building development in Sarawak

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Abstract

Purpose – Green building development practices reduce carbon footprint and promote sustainability in the built environment. To foster green building construction in Malaysia, several strategies and sustainability metrics like the Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) have been established. Yet, the implementation of green office building development in Sarawak still remains low. Therefore, the purpose of this paper is to develop MyCREST Embedded Framework (MEF) for enhancing the adoption of green office building construction in Sarawak.

Design/methodology/approach – To achieve the research aim, document analysis of the overarching MyCREST Reference Guide was conducted. Then, questionnaire was used to survey 120 green construction professionals in Kuching, the capital of Sarawak. Afterwards, data from the questionnaire was analyzed using Statistical Package for Social Science software version 22. As a result, the significant strategies for enhancing the adoption of green office building construction in Sarawak were identified, and ranked hierarchically using the Relative Importance Index.

Findings – The established significant strategies include: government policies and incentives, sustainable technological practices, defined process for executing green building projects and adequate information for the public. Moreover, this study recommends MyCREST as the suitable Green Building Assessment Tool for developing green office buildings in Sarawak due to its integration of carbon reduction strategies with sustainability indicators.

Research limitations/implications – This study is limited to Kuching; hence future study should be extended to other cities in Sarawak.

Originality/value – Based on the findings, the MEF is developed to enlighten the industry practitioners on the approaches that will elevate green office building development in Sarawak.

Keywords Malaysia, Green building, Green technology, Green framework, MyCREST, Sarawak

Paper type Research paper

1. Introduction

The building construction sector consumes approximately 50 percent of the world’s total energy, 16 percent of water, and emits about 30 percent of greenhouse gas, especially carbon dioxide (CO₂) (World Watch Institute, 2015). In USA for instance, commercial buildings accounts for nearly 40 percent of total energy production (US Department of Energy, 2008). While in Europe, buildings consumed about 59 percent of the total electricity produced in 2013 (Jing et al., 2017). In tropical countries like Malaysia, buildings generate about 25,000 tons of waste (Hassan et al., 2014). Thus, sustainable building construction which is also known as green building construction, was initiated to reduce the impact of the building sector on our natural environment. According to Ohueri et al. (2018), green building...
construction was initiated to deliver efficient and affordable building projects that supports social welfare of the occupants, and promote environmental and economic development.

Before a building is certified green, it has to be assessed using Green Building Assessment Tools (GBATs), to ascertain whether it meets specified sustainability standards. This has prompted the establishment of several GBATs across the globe. In Malaysia particularly, various GBATs have been established as a benchmark for green building development. Recently, the Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) was established. According to JKR and CIDB (2016a, b), MyCREST is a performance-based standard that links sustainability indicators to carbon emission criteria throughout the buildings lifecycle. Besides, scholars such as Bohari et al. (2016), Sim and Putuhena (2015), etc., have conducted studies on strategies for promoting green building construction in Malaysia.

In Sarawak, green building development have not been widely adopted compared to other states in Malaysia such as Selangor and Penang. Although the Sarawak Corridor of Renewable Energy (SCORE) was established to promote sustainability across various industries; construction is not listed among the priority industries that will benefit from the sustainable strategies of SCORE (RECODA, 2018). Few researchers: Niig (2016), Zainordin et al. (2018), etc., conducted study on the perception of stakeholders toward green building development in Sarawak. However, no particular study has been conducted on strategies for enhancing green building construction in Sarawak till date. As a result, green building construction in Malaysia especially in Sarawak, has witnessed a sluggish growth. As viewed by Zainordin et al. (2018) the green building construction practices in Sarawak still remain unexplored by both academic research and industrial practices.

Therefore, it is paramount to devise a framework that can be used to enhance the adoption of green office building construction in Sarawak. Additionally, this study proposes the embedding of MyCREST into the devised framework to provide a holistic approach toward carbon reduction and promotion of socio-economic aspects of sustainability throughout the building's lifecycle. The subsequent sections of this paper provide a literature review as background information to sustainable/green building construction, outline the methodological approach and present the recommendation in line with the findings.

2. Overview of green building development

Green building construction is the practice of developing buildings using resource-efficient and environmentally responsible processes throughout the building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction so as to reduce energy use, overall building cost and promote occupants healthy living (EPA, 2016). The benefits of green building are enormous. As reported by McGraw-Hill Construction (2013), the environmental benefits include efficient use of energy, water and other resources; reduction of waste, pollution and environmental degradation. The economic benefits are in the form of the reduction of operating costs by 14 percent; optimization of life-cycle economic value by 8 percent; and improvement of occupants' productivity up to 10 percent. The social benefits are enhancing aesthetic qualities; minimizing strain on local infrastructure; and improving occupants' overall quality of life.

Green building development focuses on six main principles: optimization of site design by selecting sites with easy access to basic infrastructure, and designing the building orientation, envelope, windows, etc., based on the site conditions; efficient use of water by adopting ultralow water urinals and high-efficiency toilets which uses only 0.125 to 1.6 gallons per flush, compared to 3.5 gallons per flush by conventional buildings (World Watch Institute, 2015); use of cost efficient and environmental friendly materials with less Volatile Organic Compound emissions (WBDG, 2012); improved indoor environmental quality by maximizing day lighting, and use of appropriate ventilation and moisture control...
approaches (WBDG, 2012); enhanced building acoustic performance through strategic positioning of the building farther from outdoor noise sources, right-sizing of rooms and use of materials with high insulating value (Melton, 2013); and reduction of construction and demolition waste via the establishment of waste management strategies.

In line with the aforementioned principles, several GBATs have been established to efficiently guide the development of green buildings globally. For instance, in UK, the Building Research Establishment Environmental Assessment Method (BREEAM) was established; in USA, the Leadership in Energy and Environmental Design (LEED) was initiated; In Korea, Green Standard for Energy and Environmental Design was developed; in Hong Kong, the Building Environmental Assessment Method Plus was introduced; in Singapore, the Green Mark was implemented, etc. In Malaysia, several green GBATs have also been established.

3. Green building development strategies in Malaysia context

Buildings in Malaysia consume approximately 48 percent of the total electricity (Hassan et al., 2014); and emits about 30 percent of CO₂ (JKR and CIDB, 2016a, b). Besides, Begum and Pereira (2011), reported that office buildings in Malaysia consume more energy and emits more CO₂ compared to residential buildings. As a result, Malaysia initiated several national policies including the 8th Malaysian Plan (2001–2005) up till the 11th Malaysia Plan (2016–2020), to promote sustainable building construction. The Government has also introduced the Revision of the Uniform Building By-Laws to incorporate the Malaysian Standard: Code of Practice on Energy Efficiency and Renewable Energy for Non-Residential Buildings (MS1525). Specifically, government encourages the application of renewable energy and energy efficiency in buildings, such as solar photovoltaics, rainwater harvesting, and the phasing out of incandescent lighting in building design.

Moreover, several GBATs have been introduced in Malaysia to encourage green building development practices. The Green Building Index (GBI), is the first comprehensive rating system developed in Malaysia. Afterwards, other GBATs were developed which include Green Performance Assessment System (GreenPASS), Green Real Estate (GreenRE), etc. (GreenRE, 2017; Hamid et al., 2014). However, the abovementioned GBATs have been heavily disparaged due to some shortcomings. For instance, CleanMalaysia (2018) postulated that GBI rated office buildings consume high energy compared to Green Mark rated buildings in Singapore. Besides, none of the other GBATs provided a holistic sustainable assessment of the building throughout its whole life cycle (Hamid et al., 2014).

3.1 Malaysian carbon reduction and environmental sustainability tool (MyCREST)

Due to the gap that exists in the aforementioned GBATs in Malaysia, the MyCREST was implemented. As reported by JKR and CIDB (2016a, b), MyCREST aims at quantifying and reducing built environment’s impact in terms of carbon emission and environmental implication, with a more holistic approach toward integration of socio-economic aspects of sustainability to the built environment and urban development in Malaysia. MyCREST certification award focuses on three phases (design, construction, and operation and maintenance), offering the fundamental rating tools/scorecard. Additionally, the MyCREST rating system represents a five-tier system ranging from one-star to five-star rating. In order to earn one star, a range between 40 and 49 percent of the total score must be achieved. While to have five-star rating, a score of 80 to 100 percent ought to be achieved (JKR and CIDB, 2016a, b).

MyCREST supports integrated design process and collaborative design; which facilitates green building development and enhances building sustainable performance. Also, carbon assessment method and metrics are fully integrated into the sustainable framework of MyCREST scorecard (JKR and CIDB, 2016a, b); making it a unique tool for
promoting green building practices. These essential concepts of MyCREST framework is paramount toward the development of a highly efficient building projects which will give clients value for their money, promote the occupants’ quality of health, and reduce environmental impact of the built environment especially in reducing carbon footprint. Hence, this study recommends MyCREST as the suitable GBAT that will attract stakeholders to embark on green building projects in Sarawak, because it provides a fresh stance to the development of green buildings, starting from inception to demolition, thereby providing an all-inclusive approach which facilitates the accomplishment of sustainable development goals in Malaysia (JKR and CIDB, 2016b).

3.2 Studies on promoting green building development in Malaysia
Apart from the abovementioned policies, scholars have identified numerous strategies for enhancing green building development in Malaysia. For example, a study conducted by Sim and Putuhena (2015), highlighted that holistic thinking and decision making, and more innovative solutions are the most important strategy to enhance sustainable construction in Malaysia construction industry. Bohari et al. (2016) reiterated that government policy and enforcement, provision of adequate information to clients, and provision of incentives are the primary factors to push green building enhancement in Malaysia. Ali et al. (2016), opined that green initiatives should be encouraged at the initial stage of green building design.

However, the abovementioned studies have been criticized due to obvious limitations. According to Chan et al. (2017), most of the studies on green building adoption strategies lack empirical evidence. For instance, the study conducted by Sim and Putuhena (2015) was only a review paper with no empirical evaluations. Although the Bohari et al. (2016) conducted an empirical research, their study was limited to only four interviewees. Also, Ali et al. (2016) focused only on contractors, rather than many other construction professionals. Moreover, most of the existing practices and studies on green building development focused on Kuala Lumpur, ignoring other states in Malaysia. Hence, the paradigm shifts toward the adoption of green building technology in Malaysia is still at a slow pace compared to other nearby countries like Singapore. This is evident in GBI (2018), CREAM (2017) report that as of June 15, 2018, only 452 and 6 buildings have been certified green in Malaysia, using the GBI rating tool and MyCREST, respectively. Besides, most of the certified buildings are in Kuala Lumpur, the capital of Malaysia. While other states like Sarawak have witnessed low adoption.

4. Green building construction in Sarawak
Sarawak, the largest state in Malaysia, is rich in natural resources such as timber, oil palm, high quality kaolinitic and ball clay, silica sand, etc.; generating over RM31.5bn in revenue (Yii, 2017). In order to efficiently harness these natural resources, the Sarawak government established several strategies in line with the United Nations (UN) sustainable development goals. Among the strategies is the establishment of SCORE. Although SCORE focuses on enhancing quality of life, and sustainable urban and rural development, it did not include the construction sector in its sustainability roadmap. Besides, there are limited studies on green building practices in Sarawak, despite its social, economic and environmental benefits.

For instance, Omoregie et al. (2017), proposed the use of green cement geo-polymer and green paver block to provide lasting solutions to sustainable building construction issues in Sarawak. Zainordin et al. (2018), conducted a study on the readiness among Sarawak construction practitioners such as housing developers and contractors, toward implementing and adopting green residential concept in their project. Niig (2016), investigated the challenges in implementing green building concept among contractors in Sibu, Sarawak. However, there is no study that specifically investigates the strategies for enhancing the adopting green office building construction in Sarawak. This has contributed
to poor implementation of green office buildings in Sarawak. According to Niig (2016), the
low adoption of green office building construction in Sarawak still persist due to lack of
research and development, among other factors.

According to GBI (2018), only seven office buildings have been certified green in the state
of Sarawak, as of August 15, 2018. Moreover, no building has been certified with other
Malaysian assessment tools such as MyCREST in Sarawak (Ohueri et al., 2019). This is very
poor, considering the fact that Sarawak is the largest state in Malaysia with vast building
stock. Therefore, in order to achieve the research aim, this study investigates the factors that
hinder the adoption of green building development.

5. Barrier factors to the adoption of green office building construction
Several researchers have investigated the barrier factors to green building development
across the globe. For example, Chan et al. (2016), viewed that high initial cost hinders the
adoption of green building projects across the globe. Persson and Grönkvist (2015),
identified that lack of policy and green building codes, the unsupportive attitude of end
users toward energy efficiency, and the lack of life-cycle perspectives are the biggest
barriers to the uptake of energy-efficient houses in Sweden. According to Azeem et al. (2017),
lack of information on the benefits of green building practices is among the critical barrier
factors to green building adoption in Pakistan.

As reported by Samari et al. (2013), lack of incentives from government have contributed to
the poor adoption of green building development in Malaysia. According to Ghazilla et al.
(2015), complexity of green building design, and lack of well-defined green building delivery
process have discouraged developers from undertaking green building projects. Also, the
inability of the construction industry to adopt emerging technologies is a significant barrier
factor to the successful implementation of green technologies (Hwang et al., 2017). Lack of
commitment by stakeholders, and poor market orientation are among the critical barriers to
the adoption of green building construction in Sri Lanka, Turkey and Malaysia (Athapaththu
and Karunasena, 2018; Aktas and Ozorhon, 2015; Samari et al., 2013).

Having highlighted the barrier factors, the next section evaluates the significant
strategies for enhancing green building construction.

6. Significant strategies for promoting green office building construction
There are numerous studies on the strategies for promoting green building construction
globally. The USA are leading the path in research and development for a more sustainable built
environment. A study conducted by CSC (2013) suggest that organizing educative and
awareness programs, mandatory model code, and provision of cash grants and tax credits are
predominantly used in the USA to promote green building at the state and local level. As a
result, the number of certified green buildings in the USA increased dramatically from 296 green
projects in 2006, to over 90,000 projects as of March 2019 (USGBC, 2019). In European countries,
a well-defined process for executing green building projects, and efficient management and
creation of public awareness have been identified as key strategies for achieving green building
enhancement in like UK and Denmark, respectively (Moini et al., 2014; Zanni et al., 2014).

In Singapore, Hwang et al. (2017) suggested that the most feasible strategies for
facilitating the adoption of green office buildings are government’s co-funding and
incentives, policies and regulations for green development, and collaboration with research
institutes. Furthermore, the development of a project management framework for green
construction has been identified as significant strategy for promoting the adoption of green
building development. Tan et al. (2011), posit that contractors’ awareness is needed for
promoting green building construction in Hong Kong.

Table I summarizes the study conducted by several researchers on the strategies for
promoting green building construction.
After highlighting the strategies for promoting green building adoption across various countries, this study takes an extra step toward the development of a framework to enable the accomplishment of the established strategies. According to Akadiri et al. (2012), framework is a structure or system for the realization of a defined strategy. Thus, this study reviews various frameworks established in previous study, to adapt a suitable framework for this study.

### 7. Framework for enhancing the adoption of green office buildings

Different frameworks have been developed by various researchers for promoting green building construction. Majority of the frameworks were developed based on the climate

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<td>SS6 Inform public of the cost and environmental benefits of green buildings</td>
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<td>SS8 Educational programs for green building development professionals</td>
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<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>SS9 More publicity through media, on the economic benefits of green buildings</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
</tr>
<tr>
<td>SS10 Information on the social/health benefits of green construction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SS11 Selection of competent green building design team</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>SS12 The use of a holistic green building assessment tools (GBATs)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>SS13 Establishment of green building associations to handle issues</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>SS14 Defined process for executing green building projects</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SS15 Availability of institutional framework for implementing green construction practices</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SS16 Use of technology such as Building Information Modelling, etc. for integrated development</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SS17 Continuous training and development of construction workforce</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>SS18 Green building construction target for all project team</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
</tr>
<tr>
<td>SS19 Sustainable building usage guide for green building occupants</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>SS20 Retrofitting existing buildings using affordable green technology</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
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</tbody>
</table>

Table I. Significant strategies for promoting green building construction
conditions of the countries where those studies were conducted. For example, Akadiri et al. (2012) proposed a conceptual framework for implementing sustainability throughout the buildings lifecycle. The framework is intended to be used in conjunction with existing assessment systems, particularly BREEAM, BEES and LEED. However, the framework was developed based on literature review, without validation from construction industry players. In Singapore, Chew and Conejos (2016) developed a research framework for green maintainability for ensuring the long-term maintainability and sustainability of existing and new green walls in tropical areas like in Singapore. Nevertheless, the study cannot be generalized for green buildings projects, as it only focuses on green walls.

In Malaysia, Sood et al. (2011) developed a framework to ensure the effectiveness of GBI implementation for the sustainable development of the building sector in Malaysia. Notwithstanding, the drawback of the framework is that the study was only a review paper without experts' opinion on the feasibility and adaptability of the framework. Moreover, the framework did not address the shortcomings of GBI such as high energy consumption of GBI rated building (Hamid et al., 2014), which was among the reasons MyCREST was established. In a more recent study, Sharif et al. (2017) proposed an implementation framework of green buildings based on five main categories: project management procedures, building design procedures, government policies, type of project execution and project staff perceptions. Nonetheless, the framework has been heavily disparaged due to limited research respondents and inability to specify the exact GBAT that should be employed during the green building development, considering that there are numerous GBATs in Malaysia.

A study conducted by Hill and Bowen (1997), proposed a multi-stage framework for enhancing sustainable construction. The proposed framework requires the application of GBATs during the planning and design, construction, operation, and even decommissioning stages of the building project. Besides, the framework is detailed, and encompasses all the principles of sustainable construction: social, economic, biophysical and technical. Due to the holistic nature of the framework and the rigor in developing the framework, this study adapts the Hill and Bowen (1997) multi-stage framework in order to develop a holistic framework for Implementing MyCREST oriented green building development projects in Sarawak particularly, and other tropical countries across the globe. The section below, explains in detail, the method that was adopted to develop the proposed framework.

8. Research methodology
First and foremost, a comprehensive literature review enabled the identification of 20 significant strategies for promoting the adoption of green building development. These selected strategies attracted considerable attention in previous studies. Then, document analysis was conducted to evaluate the overarching MyCREST Reference Guide. Afterwards, a quantitative research method (questionnaire survey) was designed based on the identified significant strategies for enhancing the adoption of green building construction. As stated by Tashakkori and Teddlie (2010), quantitative research method increases response rates and greatly enhances the analysis of collected data. The questionnaire was used to survey the population of this research which are the consultants (architects, construction engineers, quantity surveyors), academics and site supervisors.

Prior to the main data collection, a pilot survey was conducted to ascertain the reliability of the research instrument. According to Naoum (1998), a pilot survey requires testing the phrasing of the questions, identifying ambiguous questions, testing the technique used for collecting data, and measuring the effectiveness of the respondents. Therefore, a pilot study was conducted and the respondents for the pilot survey include two academics, two quantity surveyors and two architects, making it a total of six respondents. The reliability test was conducted via Cronbach’s \( \alpha \) coefficient in Statistical Package for Social Science (SPSS) software (version 22). The Cronbach’s \( \alpha \) values range from 0 to 1. Any scale below 0.4 is either
modified or deleted completely while scale of 0.70 and above is considered reliable and consistent (IDRE, 2018). Hence, the consistency scale used to denote minimum reliability in this research is 0.70. The average Cronbach’s α values for the strategies in the tested pilot questionnaire is 0.89, so the questionnaire was confirmed reliable.

After the reliability test of the pilot questionnaire, the main questionnaire was drafted and used to survey the research population. From the population, 150 research samples who are actively involved in sustainable construction were selected using Convenience Sampling Technique (CST). CST is a nonprobability sampling technique used to select samples based on their availability or willingness to participate in the survey (Etikan et al., 2016). Although critics have argued that CST has clear limitations and the findings are not generalizable due to potential bias; its importance cannot be under emphasized in terms of cost and time savings (Etikan et al., 2016). Out of the selected 150 samples, 120 participants responded to the questionnaire survey.

The data collected from the questionnaire were systematically entered into SPSS software version 22, and analyzed via descriptive statistics (weightage, mean, and standard deviation. Also, one-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of the different group of respondents. Thus, the Null and Alternative Hypothesis are defined:

Null hypothesis $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_k$,

where $\mu$ is the group mean; $k$ the number of groups. $\alpha = 0.05$.

However, if the one-way ANOVA returns a statistically significant result, we accept the alternative hypothesis ($H_A$), which is that there are at least two group means that are statistically significantly different from each other.

Afterwards, the Relative Importance Index (RII) was used to hierarchically rank the significant strategies based on their level of importance. The formula for RII is illustrated in the following equation:

$$RII = \frac{\sum W}{A \times N} (0 < RII < 1),$$

where $W$ is the weight given to each factor by the respondents; $A$ the highest weight (i.e. 5 in this case); and $N$ the total number of respondents.

9. Data analysis and discussion

A closed ended questionnaire which consists of two sections was used in this study. Section A consists of three questions which sought the demographic information of the respondents. Question 1 was designed to identify the area of specialization of the respondents. This is important to determine the perception of each group of respondents on the significant strategies that influence green building development. The analysis shows that 30 percent of the respondents are site supervisors, 25 percent are architect, 20 percent are from the educational institutions, 15 percent are quantity surveyors and 10 percent are electrical engineers. Thus, the study did not only focus on industry players, but also surveyed academics who are actively involved in research and development in the field of green building construction.

Question 2 was used to discover the respondents’ years of working experience; this is to determine the level of experience of surveyed respondents in the area of green building construction. It was discovered that 60 percent of the respondents have been working between 11 and 20 years, while 30 percent of them have worked for more than 20 years. However, 10 percent of the consultants worked below ten years. This implies that majority of respondents surveyed are experienced and have been involved with green building constructions for decades. However, some of the Academics surveyed worked for less than ten years. Yet, their experience and knowledge in green building construction cannot be underestimated, considering their enormous publications in the field of sustainable building construction.
Question 3 was used to determine whether these consultants have undergone any professional training on sustainable construction, and to determine their level of expertise. The outcome indicated that about 50 percent of the respondents have undergone formal training on sustainable construction, about 30 percent went through organizational training, while the rest went for workshops and road shows on sustainable construction. This shows that their years of working experience have contributed to their immense knowledge in the field of green building construction.

Section B used five Likert Scale of Not Important = 1, Slightly Important = 2, Important = 3, Very Important = 4, Extremely Important = 5, to evaluate the significant strategies for promoting sustainable construction in Sarawak. The analysis was aided by the use of SPSS. The weightage, mean value, and standard deviation, and the variation in their mean values (ANOVA) were calculated. Based on the Likert scale used, any significant strategy that is less than 3 is not important, as such it will be eliminated. Additionally, the RII was used to hierarchically rank the significant strategies according to their level of importance. This is displayed in Table II.

Table II displays the analysis of significant strategies for promoting the adoption of green office buildings in Sarawak. The ANOVA result indicates that there is a significant difference between mean values of the various respondents. Furthermore, there is a significant degree of agreement among the green building experts regarding the relative importance ranking of the promotion strategies. For instance, Government’s co-funding and further market-based incentives for green building development (SS1), with mean value of 4.30 and RII value of 0.86, was ranked as the most significant strategy for prompting green office building construction in Sarawak. Although the academics did not view this strategy as significant, other respondent especially the site supervisors and quantity surveyors opined that this is the most significant strategy for promoting green buildings. This corresponds with Qian et al. (2016) view that incentives from the government and other private parties, such as financial institutions have the highest level of influence in driving construction stakeholders to embrace green building construction practices. Therefore, provision of incentives is crucial to development of green office building projects in Sarawak.

<table>
<thead>
<tr>
<th>Code</th>
<th>Likert scale</th>
<th>One way ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5</td>
<td>W  Total No</td>
</tr>
<tr>
<td>SS1</td>
<td>30 24 66 516</td>
<td>120</td>
</tr>
<tr>
<td>SS2</td>
<td>30 30 60 510</td>
<td>120</td>
</tr>
<tr>
<td>SS16</td>
<td>30 36 54 504</td>
<td>120</td>
</tr>
<tr>
<td>SS14</td>
<td>36 30 54 498</td>
<td>120</td>
</tr>
<tr>
<td>SS9</td>
<td>30 48 42 492</td>
<td>120</td>
</tr>
<tr>
<td>SS10</td>
<td>33 54 33 480</td>
<td>120</td>
</tr>
<tr>
<td>SS6</td>
<td>36 51 33 477</td>
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<tr>
<td>SS17</td>
<td>36 60 24 468</td>
<td>120</td>
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<tr>
<td>SS5</td>
<td>39 60 21 462</td>
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</tr>
<tr>
<td>SS4</td>
<td>45 60 15 450</td>
<td>120</td>
</tr>
<tr>
<td>SS11</td>
<td>54 57 9 435</td>
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<td>SS19</td>
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<td>69 51 411</td>
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<td>SS3</td>
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<td>SS8</td>
<td>15 60 45 390</td>
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<td>SS13</td>
<td>27 54 39 372</td>
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<td>SS7</td>
<td>39 45 36 357</td>
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<td>SS15</td>
<td>39 48 33 354</td>
<td>120</td>
</tr>
<tr>
<td>SS18</td>
<td>45 45 30 345</td>
<td>120</td>
</tr>
</tbody>
</table>

Table II. Ranking of significant strategies for promoting green office buildings construction in Sarawak
Moreover, mandatory government policies that will alleviate poverty among the public (SS2) with mean value 4.25 and RII value 0.85, was ranked as the second most significant strategy for promoting sustainable building development in Sarawak. Although some previous studies did not include this as a strategy, studies such as Hill and Bowen (1997) and Akadiri et al. (2012) have emphasized that alleviation of poverty among the public will expose and provide them with available information and resources, to appreciate and embark on green building development. Thus, the academics hammered on the need for the state government of Sarawak, and federal government of Malaysia to devise strategies to eliminate poverty at both urban and rural areas, so as to promote wider adoption of green office buildings in Sarawak.

Another significant strategy highlighted by the respondents is the use of sustainable technology such as Building Information Modeling, etc. (SS16), with mean value of 4.20 and RII value of 0.84. According to Hwang et al. (2017), the inability of the construction industry to adopt new technology is hindering the adoption of green office building practices. All the respondents acknowledged the benefits of BIM in promoting green building development. This is evident in industry practices, and academic publication where BIM have been empirically ascertained as beneficial to achieving green building project especially at the initial stage of the project. Moreover, the use of technology has been identified as a major factor that encourages contractors and developers to embark on green building project (Qi et al., 2010).

Defined process for executing green building projects (SS14) was ranked the 4th most significant strategy for promoting green office building construction in Sarawak. Defining the green building design, construction and operation process enables the multi disciplinary design team to collaboratively use the diverse softwares to overcome the complexities of green building development. Overcoming the disjointed green building development process is a significant step toward the promotion of green building development in the construction industry (Zanni et al., 2014). This aspect has been ignored in literature studies but practitioners emphasized on the need for a green building development process model from design, construction, and operation and maintenance stages of the green building project.

More publicity through media (e.g. print media, internet, radio and television programs) on the environmental benefits of sustainable building construction practices (SS9) has been identified as the 5th most significant strategy due to the importance of information. As agreed by all respondents, the importance of information, and research and development in promoting green building development cannot be under emphasized. According to Chan et al. (2017), more publicity through media will significantly promote the adoption and acceptance of the green building concept.

However, strategies such as public environmental awareness creation through workshops, seminars, and conferences (SS7) has a mean value of 2.98; availability of institutional framework for effective implementation of sustainable construction practices (SS15) records a mean value of 2.95; and specific green building construction target for all project team (SS18) with a mean value of 2.87 has been deemed insignificant due to the fact that their mean values are less than 3.0. According to the Likert scale used in the questionnaire, any value of less than 3 is regarded as not important or insignificant. Based on the outcome of the analysis, four significant strategies for enhancing green office building adoption in Sarawak have been identified and used as the main categories for the development of a comprehensive framework for enhancing green office building construction practices in Sarawak.

10. MyCREST embedded framework for enhancing the adoption of green office building construction in Sarawak
Based on the four significant strategies identified through empirical survey and analysis, this study develops a framework for enhancing the adoption of green office buildings in Sarawak. The strategies in the framework will tackle critical barrier factors hindering the adoption of green building development in Sarawak. The framework was adapted from the
framework for attaining sustainable construction proposed by Hill and Bowen (1997). As reiterated by Hill and Bowen (1997), developing a framework for promoting the adoption of green building development ought to be accompanied by a suitable green building development guide or matrix. Thus, this study evaluated the existing GBATs in Malaysia and identified MyCREST as the most suitable GBAT to be integrated in the proposed framework. As a result, MyCREST is embedded in the framework to actualize its full potential of enhancing the adoption and performance of green buildings in Sarawak. Embedding MyCREST into the framework will enable stakeholders to accomplish the sustainability principles, while emphasizing on reducing CO2 emission (JKR and CIDB, 2016a, b). Figure 1 depicts the framework work for enhancing MyCREST oriented green office building development in Sarawak.

Figure 1 is the developed framework for promoting green office building development in Sarawak. First and foremost, the framework recognizes the need for a holistic GBAT that will be adopted throughout the building’s life cycle. Hence, the Framework suggests that the green building development in Sarawak should comply with MyCREST design, construction, and operation and maintenance categories to reduce carbon footprint and promote sustainability. This is in line with UN Agenda 21 for Sustainable Construction for developing countries which aim at promoting sustainable construction at both local and international level. Also, it corresponds with Malaysian Green Technology Master Plan 2017–2030, that targets 45 percent reduction of CO2 emission by 2030 (KeTTHA, 2009).

Then, the framework is developed based on the identified four most significant strategies for promoting green office building development in Sarawak. As shown in the framework, government policies and incentives is the first strategy toward green building development in Sarawak. Government must play a fundamental role, if green office buildings should be promoted in Sarawak. Specifically, government should provide incentives and enforce green building policies that will promote the adoption of green building development in Sarawak. As opined by Qi et al. (2010), government should provide green building regulations and incentives that will influence contractors toward the adoption of green building construction practices. Also, poverty eradication will promote the adoption of green building development (Akadiri et al., 2012).

Also, sustainable technological practices ought to be adopted. One of critical barriers to green building development is poor technological adoption due to lack of trained construction workforce (Hwang et al., 2017). Thus, adopting BIM technology should be accompanied by training of multi disciplinary team to get acquainted with the diverse domain softwares for building modeling, building performance analysis and information exchange. This will reduce the complexities in green building development which fundamentally contributes to the poor adoption of green building practices among construction companies in developing countries. As viewed by Chan et al. (2017), technology adoption and training is paramount toward the enhancement of green building development.

Furthermore, the green building development process ought to be defined precisely to encourage collaborative project delivery. According to Zanni et al. (2014), it is necessary to develop a green building process model to facilitate green building development and also enhance the sustainability performance of the building project throughout its life cycle. Therefore, the MyCREST Embedded Framework (MEF) advocates the establishment of a clearly defined green office building process model to encourage collaboration among project team which will in turn encourage construction stakeholders in Sarawak to embark on green building development practice.

In addition, MEF has emphasized on the importance of creating adequate awareness to the public on the social, economic, and environmental benefits of green office buildings. The misconception that green office buildings projects are expensive should be corrected by providing the public with accurate and verified information on the benefits of green office buildings.
11. Conclusion
Despite the increasing interest and sustainability benefits of green building development; its adoption in Sarawak still remains low (Zainordin et al., 2018). Thus, this study tends to promote the adoption of green office buildings practices in Sarawak. First of all, the barrier factors to the implementation of green building development were investigated. Afterwards, the strategies for enhancing the adoption of green office building construction in Sarawak were evaluated and 20 significant strategies were identified through critical review of related literature. Then, a questionnaire survey was conducted on construction professionals and the top four significant strategies that greatly promote
green building development were identified and they include: government policies and incentives; sustainable technological practices; defined process for executing green building projects; and adequate information for the public. This corresponds with various studies: Darko et al. (2017), Chan et al. (2017), Zanni et al. (2014) on green building enhancement strategies.

Based on the findings, and the potentials of MyCREST in reducing carbon emission and promoting sustainability in the built environment, this study developed the MEF for enhancing the adoption of green office building construction in Sarawak. Given the limited empirical studies on the strategies for promoting the adoption of green building development in Sarawak, the empirical results of this study make a significant contribution to the green building body of knowledge. Moreover, the findings of this study can serve as a valuable reference for assisting practitioners and policy makers in the development of practical strategies for promoting green building development, achieving the targeted MyCREST points, and enhancing the sustainable performance of the building. However, this study is limited to specific stakeholders in Kuching, the capital of Sarawak. Thus, further study is needed to investigate other stakeholders such as policy makers, manufacturers, suppliers and transporters across various cities in Sarawak.

References


BEPAM

10,2


Further reading


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Renewable energy sources and technologies in commercial buildings

Understanding the Nigerian experience

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Abstract

Purpose – The purpose of this paper is to explore the perceptions and experiences of building practitioners in the adoption of renewable energy (RE) in commercial buildings in Nigeria.

Design/methodology/approach – A qualitative methodology was used guided by the principles of the Grounded Theory Method (GTM). Data were collected using in-depth semi-structured interviews with a purposive sample of five industry practitioners.

Findings – Five distinct factors emerged, namely, being compliant, change in mindset, normalising, being autonomous and identity. The research revealed the significance of contextual (cultural) peculiarities and the role identity plays in informing RE adoption. The findings substantiate the significance of RE adoption in the future practice of building practitioners and in ensuring environmental stability within the Sub-Saharan Africa (SSA) context.

Research limitations/implications – The study focuses on commercial office buildings and attempts to provide contextual grounding to inform theory generation as part of a wider study.

Originality/value – This research contributes methodologically and empirically by providing grounded insight into the adoption of RE in commercial buildings. Thereby, enabling a much greater understanding of the issues associated with enhanced promotion and adoption by professionals and stakeholders, which can inform policy interventions. Furthermore, it will benefit further research within the SSA context and provide valuable lessons associated with adopting GTM in construction research.

Keywords Nigeria, Sub-Saharan Africa, Renewable energy, Sustainable building, Commercial building, Grounded Theory Method

Paper type Research paper

1. Introduction

It is widely acknowledged that energy is central to both the world’s opportunities and challenges (Keho, 2016). This has placed significant emphasis on the need to utilise renewable energy sources in response to global climate change (IPCC, 2014). According to the IPCC (2014), the building industry plays a dual role as the problem and solution. First, it is one of the highest contributors to greenhouse gas (GHG) emissions, and second, it has the greatest potential to reduce GHG emissions in a cost-effective way. As such, global climate concerns have increased awareness of the need for sustainability practices in the construction industry. Consequently, this has led to the development of measures to manage resources and mitigate against the environmental impact of building projects in the entire building process (Dalibi et al., 2017). This has resulted in the development of the Green Building Councils (GBCs) and other environmental standards worldwide (Painuly, 2001).
Green buildings (GB) have been viewed as being capable of achieving sustainable development (Chan et al., 2017), by enabling holistic, optimised and integrated building solutions through the use of renewable energy (RE) technologies and sustainable practices (Lockwood, 2006).

The International Renewable Energy Agency (IRENA, 2016) notes that whereas most developed countries have prioritised GB standards, most notably, the UK with the Building Research Establishment’s Environmental Assessment Method and the US with Leadership in Energy and Environmental Design (LEED), this is not the case in most developing countries within the Sub-Saharan Africa (SSA) region. In fact, South Africa is the only country within the SSA region, with a fully established GBC and environmental rating system, Green Star SA (WGBC, n.d.). Other countries such as Kenya and Ghana, while in the process of establishing such councils and rating systems (WGBC, n.d.), have adopted the Green Star SA. Other countries, such as Nigeria, have unofficially adopted LEED as a rating system (Usman and Mohd, 2012) on an ad hoc basis.

According to the IEA (2016), Africa’s GHG contribution is considered insignificant, at circa 4 per cent, in comparison to China’s 28 per cent, which is the highest in the world. The IEA (2016), however, recognises Africa’s increase in GHG emissions as its countries industrialise, with Lotfabadi (2015) attributing the problem of future GHG emissions to developing countries. With respect to the SSA region, it has been identified as one of the most concentrated energy deficit areas in the world (The World Bank, 2017), with 62.5 per cent of the region’s population without electricity access (IEA, 2017). In addition, developing countries are predicted to account for 90 per cent of the world’s population growth by 2025 (Blowers, 2013). Thus, the significance of managing SSA’s GHG emissions to enable preparedness and effective environmental management cannot be overstated. This study, whilst presenting selected energy data on SSA, focuses on the Nigerian context.

2. Background

Access to stable, reliable and affordable electricity has become an esoteric idea to most in Nigeria (Africa Progress Panel, 2015). The country has the second largest energy deficit in the world after India (The World Bank, 2017). This has resulted in a number of unsustainable practices, such as the widespread use of fossil-fuelled backup power generators (IEA, 2017). Existing empirical studies highlight the country’s energy crisis and its implication to businesses and individuals (see Oseni, 2016; The World Bank, 2014). According to Awofeso (2011), 90 per cent of businesses and 30 per cent of residences in Nigeria have their own power generating sets. The country is currently the largest generator importer in Africa (IEA, 2014) and the second largest GHG contributor in Africa, after South Africa (Ritchie and Roser, 2019). The Nigerian Government acknowledged the severity of the energy crisis, in its 2015 power baseline report (Federal Government of Nigeria, 2015). Table I presents a country-comparative energy and GHG emissions analysis.

<table>
<thead>
<tr>
<th>Country</th>
<th>Population 2016 (est. million)</th>
<th>Electricity consumption 2014 (kWh/capita)</th>
<th>Population without access to electricity 2016 (est. million)</th>
<th>CO2 emissions/capita vs GDP/capita 2016 (metric tons/$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nigeria</td>
<td>185.99</td>
<td>144</td>
<td>75</td>
<td>0.55/5,360</td>
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<tr>
<td>Egypt</td>
<td>95.69</td>
<td>1,658</td>
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<td>South Africa</td>
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</tbody>
</table>

The Nigerian Government also notes a 75 per cent loss of generated energy due to inefficiencies. For example, it has an installed energy-generating capacity of circa 12,522 MW but produces a distributed capacity of only 3,115 MW. In addition, self-power generation costs are about twice that of grid-based power. Consequently, Nigeria is beginning to take strides to diversify its energy mix and improve energy security by increasing its RE share. This is being achieved through several initiatives and policies, such as the Renewable Energy Master Plan (REMP) (Nachmany, 2015). However, it is recognised that these initiatives are not focussed on power for the built environment (Waniko, n.d.). It is also acknowledged that the country has an abundant RE resource, which is able to meet its domestic needs (Africa Progress Panel, 2015) and consequently change its social, economic and environmental landscape. However, hydropower is the only RE source contributing to the on-grid electricity system, accounting for 20–30 per cent (Federal Government of Nigeria, 2015). Biomass (fuelwood) is the energy source that is used the most throughout Nigeria, contributing to an off-grid system, accounting to 82 per cent of energy use. However, it is primarily used traditionally in rural areas (Ley et al., 2014). Other energy sources, such as wind and solar energy, are currently being exploited (Ohunakin et al., 2014).

Traditionally, solar use has been limited in the country, with existing literature revealing its use, primarily on small scale and isolated applications in rural areas for residential and community use (Sambo, 2010), as well as one-off independent use by private individuals and government (Oseni, 2016). However, its level of adoption in commercial buildings is not known (Onyekuru and Marchant, 2012; Arup Nigeria, 2016). This is of importance, as commercial buildings have been identified worldwide as high-energy users, as well as viable platforms for RE integration (Heinstein et al., 2013). In addition, as commercial buildings in Nigeria are designed to be independent of utility services, due to the country’s infrastructural poverty, providing services such as water, sanitation and other related services (The World Bank, 2014), places an additional burden on energy requirements. As such, electricity provision is over-designed for, with redundancies to minimise disruption to business operations (Leishman et al., 2012), resulting in the need for prolonged generator operations. This had led to commercial office buildings having up to four fossil-fuelled power generators depending on the criticality of work performed. REs have the potential to be integrated into commercial buildings and thereby reduce the dependence on unsustainable energy-generating practices. Therefore, the study seeks to explore the perceptions and experiences of building practitioners in the adoption of RE in commercial buildings in Nigeria.

3. **Renewable energy adoption in buildings**

RE, also referred to as clean energy resources, is described as natural and unlimited resources derived from the sun (indirectly or directly) or from natural movements of the environment such as wind, hydropower, photo-electric and tidal (Ellabban et al., 2014). RE is widely recognised as being capable of meeting the world energy demands if optimally utilised (Lotfabadi, 2015). Their use promotes sustainable practices and environmentally responsive buildings (IPCC, 2007) and thereby, mitigates against the adverse effects associated with construction activities (Dalibi et al., 2017). RE adoption has also been noted as enhancing market options, thereby creating competition, which, in turn, leads to reduced cost of technologies, as well as creating employment opportunities (IEA, 2015).

According to Reddy and Painuly (2004), the move to RE from non-RE should be given priority, due to its benefits. However, despite this, there exist extensive adoption issues (Dalibi et al., 2017), with RE only contributing circa 13 per cent of total world energy supply (Sen and Ganguly, 2017).

RE, like all aspects of sustainability, faces challenges to its adoption and/or building integration. According to Amaratunga et al. (2002), sustainability in the context of the built
environment is multifaceted and complex, as such, its understanding and the significance attributed to it varies both at country and stakeholder levels. Thus, perceptions play a key role in determining adoption, which according to Chandra and Loosemore (2010) have positive or negative impacts on a project. This is reflective of the studies amongst others, which identify barriers and drivers as the two overriding themes in RE adoption, based on perceptions of stakeholders such as architects, engineers and facility managers. Thus, there is a need to understand the perceptions of stakeholders (Chinyio and Olomolaiye, 2009), which Painuly (2001) opines functions as the gap finders.

Prevalent in literature is research on stakeholder perceptions on RE adoption in developed countries, in both residential (Balcombe et al., 2013; Leggett, 2014; Yamamoto, 2015) and office buildings (Jones, 2002; Warren, 2010; Zhang et al., 2012). However, research on its adoption in the SSA region is limited (du Plessis, 2007; Katikiro, 2016; Darko et al., 2017). In particular, there is limited empirical studies that have focussed on RE in commercial buildings in SSA. This is of importance, as only when the issues associated with RE are recognised, its full potential through adoption can be realised (Painuly and Fenhann, 2002).

Available research in the SSA context focuses on residential buildings (Oliver et al., 2010; Barry et al., 2011; Ahlborg and Hammar, 2014; Ugulu, 2016) but it is, however, important to note that empirical studies on RE in residential buildings in SSA have primarily adopted pre-defined frameworks for selection of influencing factors informed by literature aligned to developed countries (Painuly, 2001; Katikiro, 2016). For example, the studies by Ahlborg and Hammar (2014) in Tanzania and Mozambique and Oliver et al. (2010) in South Africa both initially identified barriers through a review of literature which then informed further study for validation. The use of pre-formed processes imposed restrictions on the understanding of context-based barriers. There is a need to recognise that one size does not fit all, especially in relation to sustainability (OECD, 2001). This raises questions of the suitability of the use of pre-formed list of barriers when researching sustainability issues in developing countries, which is predominantly the case (Katikiro, 2016; du Plessis, 2007). According to Katikiro (2016), studies in developed countries are based on models of decision-making process informed by information, regulations, and economics in quantitative methods, and typifies construction research.

However, this is not the same in developing countries, due to the lack of data and records (Onyekuru and Marchant, 2012), as well as social and economic differences (Hansen et al., 2018). This suggests that studies that adopt predefined frameworks are limited by the assumption that barriers and drivers will be similar regardless of context. However, there is evidence to the contrary, as reflected by comparative studies in natural and social science fields, including studies in the built environment (see Painuly and Fenhann, 2002; Rupf et al., 2015).

The imposition of predefined frameworks will have implications on how concepts and methods are promoted and implemented in developing countries. According to du Plessis (2007), there is an urgency for broadening the scope of research in developing countries to enable a better understanding of inherent situations, in order to ensure accurate and valid empirical findings and knowledge, which will ultimately influence strategies for sustainable development. This is echoed by Laryea and Leiringer (2012), Murtagh et al. (2016) and Darko et al. (2017). Ugulu (2016) advocate for comprehensive research in developing countries, due to their contextual and unique issues as opposed to adopting generalised problems associated with developed countries. Thus, factors influencing adoption (positively or negatively) identified in one country would not simply be applied to another country (Trevarthen, 2011), especially in the context of developed and developing countries.

According to Murtagh et al. (2016), Ugulu (2016) and Hansen et al. (2018), there are a number of issues and concepts representative of developing countries that are unknown to and/or not experienced by developed countries such as co-production, limited or lack of access of electricity, self-help and external dependencies. As such, the aforementioned issues
and concepts can be taken for granted in developed countries and consequently, not taken cognisance of in research. In addition, Murtagh et al. (2016) and Traverthen (2011) note that much of the research in the construction industry has focussed on technological and economic aspects of sustainability, as well as adopting quantitative approaches, failing to give in-depth insight (Dainty, 1998; Katikiro, 2016).

This study took a similar approach to the studies, which presents a strong argument for research in the SSA region and wider African context. It adopted the Grounded Theory Method (GTM) as a strategy to the enquiry, due to the dearth of empirical research and literature on RE adoption in commercial (office) buildings in SSA. Thereby, facilitating grounded in-depth insight from building practitioners’ perspectives, which are invaluable to understand the issues in context.

4. Method

GTM is an interpretive research approach, described in the literature as a naturalistic, flexible and a systematic process grounded in data, leading to theory generation (Charmaz, 2014). Literature presents varied approaches to GTM, namely, classical, structured qualitative analysis and constructivist (Charmaz, 2014). However, the approaches have similarities with the main features being coding and constant comparative analysis, immediate analysis of data, memo writing, theoretical sampling (Engward, 2013). The choice of using GTM was informed by the initial research question posed and the nature and field of the study. In this case, the research was interpretivist and sought to gain an in-depth understanding of building practitioners’ perceptions and experiences within the context of sustainability in the built environment. According to Braun and Clarke (2013), GTM is best suited to inquiries about influencing factors and understanding the underpinning processes of a situation, which was central to the study. As such, the study was guided by the participants, allowing for a natural process without constraints. In addition, GTM is also applicable in the context of SSA, as it enables in-depth data grounded in that particular context and not pre-defined by any existing frameworks (Hussein et al., 2014). The study was guided by the fundamental principles of GTM, and not any approach, so as not to stifle flexibility, creativity and emergence. However, GTM offers the opportunity to refine, modify and evolve the methodology to enable any potential limitations to be overcome.

4.1 Setting, sampling and recruitment

The study was conducted in Lagos, Nigeria adopting a purposive sampling strategy to guide the selection of the participants. The rationale for this was to select participants best suited to provide insight (Larsson and Poel, 2002), as well as being the initial stage of sampling in GTM (Glaser, 1978). Thus, building practitioners being the decision-makers in the building (design) process, offering differing perspectives were chosen. A sample size of five participants was used, which was considered suitable, as the study focussed on achieving quality and robustness in the analysis as a foundation for further research as opposed to generalised representation (see Baker and Edwards, 2012). The sample was recruited from a personal network of contacts and consisted of: an architect with 36 years’ experience (AR.36); a mechanical engineer with 35 years’ experience and a PhD candidate (ME.35); an electrical engineer with 25 years’ experience and Bachelor’s degree (EE.25); a facilities manager with 13 years’ experience and a PhD (FM.13), and a structural engineer with 25 years’ experience and an Master’s degree (SE.25). All participants were registered members of their relevant statutory and professional bodies.

Ethical approval was obtained for the research and all participants gave written consent for use and dissemination of information and for the interviews to be recorded. Voluntary participation and withdrawal were ensured, and confidentiality was protected.
4.2 Data collection

All interviews were conducted face to face and lasted on average 60 min. Semi-structured interviews with open-ended questions were used in the study and were considered appropriate based on the study aim (Patton, 1990). Questions designed to elicit participants’ opinions about REs were asked, with broad initial questions, leading to more specific questions to gain deep insight and rich information. For example, some of the questions included; “Can you please tell me about your profession?”, “How would you describe the design process in Nigeria?” and “Tell me about what comes to mind when you think about the term sustainability?” An interview guide was developed and vetted for clarity and to limit interviewer bias (Charmaz, 2014). This, however, evolved during the process, taking into consideration new areas of inquiry, due to participant responses and the differing participant disciplines. Thus, the interview guide progressed in line with the analytical process. All interviews were digitally recorded and transcribed by the researcher, with memos written throughout the data collection process.

4.3 Data analysis

Coding and constant comparative analysis. Described as the core process in GTM, data analysis is undertaken through constant comparison of data sets from codes to categories to concepts for theoretical development (Evans, 2013). This process allows the researcher to maintain a close connection with the data, and it was achieved through coding of interview transcripts and memos (Charmaz, 2014). Data analysis was undertaken manually, using diagrams and computer software such as Excel and Microsoft Word, and started after the first interview, continuing with subsequent interviews, comparing interview data with one another. All interviews were transcribed and coded using gerunds, which are verbal nouns (ending in “ing”) and enable the analysis to focus on participant actions (Charmaz, 2014). Coding was conducted in stages, commencing with open coding; using a line-by-line coding process, which identified codes and meaning from the transcribed text. This process was repeated for each participants’ response developing into focused coding. Table II illustrates an example of the coding process.

According to Charmaz (2014), gerunds emphasise processes and actions and the initial interviews identified several processes and generated many codes. For example, this included codes that captured how building practitioners reacted and/or responded to sustainability adoption, sought out information on RE and their practices associated with generators. One of such codes that emerged and labelled as a focused code titled “being knowledgeable about sustainability issues” captured processes which appeared significant/central to the practice of building practitioners, in relation to the adoption of sustainability (practices and renewable energies) in commercial buildings. As well as, its regular presence in the discussion across the varied disciplines. Using this constant comparative method with the aid of analytical memos the categorisation of focussed codes was distinguished, which enabled the emergence of the category “being compliant”.

Memo writing. Memos are highly recommended in GTM, as they offer a key process in facilitating further data collection and analysis (Corbin and Strauss, 2015). Three types of memos were written throughout the research, namely, a reflective memo (personal journal), key point’s summary (case-based memo), written after each interview and analytical (conceptual) memo. The memos served to articulate non-verbal aspects during interviews, ensure reflexivity; articulating the researchers thought process, any changes and implications, as well as development form initial codes to categories (aiding theory generation). It was also prudent not to rely solely on audio recordings. The emerging ideas were fit into categories, which involved the use of all the memos produced during the study. The memos helped to formulate the storyline by relating categories, validating
relationships and identifying gaps requiring further development. Interviews were also re-analysed, which helped to ensure the analysis process was grounded in the data (Glaser and Strauss, 1967).

5. Findings and discussion

Five initial categories representing the perceptions and experiences of building practitioners to the adoption of RE in commercial buildings in Nigeria were revealed as shown in Table II and discussed below.

5.1 Being compliant

This was identified as becoming a standard, the norm for participants, primarily working with international clients, who identified sustainability as a major concern. International clients (developers and businesses) were identified as driving RE adoption, by enforcing compliance through consultant appointment agreements. Participant ME.35 noted consideration of sustainability as a prerequisite for an appointment with, an international client, saying: “We also work with a lot of the internationals we have to consider it, I mean we see clauses […] if you are working with an international of which the issue of sustainability and climate change is an issue, you have to include it, you have to consider it”. Thus, illustrating that international clients as the building commissioners were exercising their power and directing the process to suit their requirements. Also, Nigerian standards were seen by participants as less stringent than international standards, with international standards often referred to in Nigerian building documentation. As such, international standards were generally followed. Participants also noted that most international clients had a sustainability policy, which also informed their drive for adoption of RE and sustainable practices. This was noted by Participant AR.36: “They actually have a green bank philosophy or something […] So, this project is one of the first major ones they would

<table>
<thead>
<tr>
<th>Initial coding</th>
<th>Focussed coding</th>
<th>Category</th>
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<tbody>
<tr>
<td>Enforcing sustainability through contractual</td>
<td>Being knowledge about sustainability issues – (Driving sustainability)</td>
<td>Being Compliant</td>
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<tr>
<td>agreement</td>
<td></td>
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<tr>
<td>Using building to reflect sustainability advocacy</td>
<td></td>
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<tr>
<td>Using LEED as a status symbol</td>
<td>Seeking accreditation/recognition</td>
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<tr>
<td>Adopting PV to make a statement</td>
<td></td>
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<tr>
<td>Acknowledging global impact of climate change</td>
<td>Taking ownership - Thinking of sustainability</td>
<td></td>
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<tr>
<td>Assessing role in relation to environmental impact</td>
<td></td>
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<tr>
<td>Changing approach to sale of space</td>
<td>Using sustainability as a marketing strategy</td>
<td></td>
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<tr>
<td>Using LEED as a marketing tool</td>
<td>Designing for sustainability</td>
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<tr>
<td>Considering environmental health in design</td>
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<tr>
<td>Reducing reliance of generators</td>
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<tr>
<td>Paring solar with other sources</td>
<td>Pairing energy sources</td>
<td></td>
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<tr>
<td>Reducing pollution with shared power</td>
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<tr>
<td>Accepting generators as the norm</td>
<td>Accepting/maintaining the status quo</td>
<td>Identity</td>
</tr>
<tr>
<td>Being comfortable and trusting with what is known</td>
<td></td>
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</tr>
<tr>
<td>Lacking government support (initiatives)</td>
<td>Lacking enabling environment</td>
<td></td>
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<tr>
<td>Lacking empirical evidence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relying on generators/foreign facilities</td>
<td>Entrenched beliefs and systems</td>
<td></td>
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<tr>
<td>Being sceptic and having distrust in institutions</td>
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<tr>
<td>Seeing climate change as a distant threat</td>
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<tr>
<td>Needing a trendsetter</td>
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<tr>
<td>Wanting to belong</td>
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Table II. Coding process
do for their own use, they agreed to put their philosophy to work”. However, Participant ME.35 suggested RE adoption primarily sought to gain sustainability certification, saying: “[… the client was emphatic on sustainability and other aspects […] the intent was to achieve LEED certification […] so it had to be included for a statement”. Both participants present varying perspectives, with Participant AR.36, relating the client’s decision based on advocacy for sustainability, with Participant ME.35 being sceptic about the client’s intention, implying it was more for recognition. The duelling perspectives are reflective of both Herazo and Lizarralde’s (2016) and Laufer’s (2003) opinions. According to Herazo and Lizarralde (2016), there is a link between stakeholders attempt to evidence their contribution to sustainable development goals and ethical stance as their reason for advocating sustainability. Whilst Laufer (2003) notes the function of advocacy as primarily a business tool. The excerpts point to the function of compliance as both external and internal drivers, informed by aspects, such as international collaboration/globalisation of business, social responsibility and reputation/prestige. It highlights the drive towards sustainability either willingly or through forced compliance.

5.2 Change in mindset
This category highlights the acknowledgement of a problem and more importantly seeks a solution. Participants emphasised efficiency as a key consideration in the design, with a focus on the reduction and conservation of resources in achieving both the client’s requirements and reduced human and environmental impact. Participant AR.36 described efficiency as the “big E”, comprising of functional, construction and energy aspects, whilst Participant FM.13 identified efficiency as informing decisions to enable the reduced environmental impact of buildings. With Participant FM.13 further noting questions such as “[…] how does it impact my ability to say I am operating a clean environment?” and “should I have alternatives?”, which were intended to act as checks for such decisions. This speaks to the appreciation of global issues and suggests that participants move towards taking ownership, making a link between their role and the impact on the environment, as well as considering the utilisation of alternative sources as a more environmentally friendly option. In addition, Participant FM.13 noted: “Today most grade A buildings in Lagos are not selling space any longer, they are selling the value space brings not only to the occupants, to the company […] that mindset will also make them start thinking about alternatives sources of power”. Sustainability is perceived as adding value beyond environmental, but also social and economic value. It speaks to a transition towards more sustainable practices. The above discussion and excerpts infer a concern and desire for change due to increased awareness of global climate change and the role participants play in contributing positively or negatively to it and the need to take ownership. In addition, there is also tangible value for the clients, leading to the exploitation of sustainability as a market mechanism tool for commercial value. This is consistent with the study by Olaleye et al. (2015), which aligned willingness to pay a premium for GB.

5.3 Being autonomous
This category highlights the users’ motivation and self-initiative for the adoption of sustainable practices from perceived personalised economic benefit, as well as overall environmental benefits. Some participants reported a move towards decentralised power generation using alternative power sources, primarily solar, either paring sources or adopting a shared power approach. Participant AR.36 explained: “One of the things that we’ve been advocating is that you have solar source to run low energy consumers […] at least it reduces the size of your mechanical fossil burning, fossil burning onsite power generating plant”, whilst Participant FM.13 suggested that designing for sustainability will influence design, ensuring that the minimum power required can be generated. Despite its
limited adoption, both participants acknowledge the benefit of solar in reducing generator pollution as well as enabling the provision of minimum power requirements through considering solar in design. In addition, most participants indicated the increasing use of gas-powered generators due to its reduced pollution levels as opposed to diesel. According to Participant ME.35: “[…] rather than burning diesel, we would rather burn gas”. This speaks to the appreciation of the environmental impact of fossil fuels and the need to mitigate against it. In general, participants recognised the need for decentralised power which presents less environmental impacts and reduced/shared cost. With decentralised power generation as the current power approach, and utility power unavailable, this appears to be the next logical step.

5.4 Normalising
This category highlights the dependence of fossil fuels as a perceived indispensable element entrenched in everyday life, as well as a comfort with what is known. As noted by Participant AR.36: “Well you know, they have been around, and we have been dependent on them for so long, that there is a lot of know-how and management skills [laughs] […]”. Participants reported the primary use of fossil-fuelled generators replacing grid power due to its epileptic supply. All participants referred to fossil-fuelled generators as a first principle consideration for power to buildings. Participant EE.25 noted, saying: “Generators are not efficient but necessary at whatever cost, you need to have it. Generators have to be part of the vernacular architecture because there is no other way”. Illustrating the acceptance of things as they are and a somewhat defeatist attitude. Participants also noted the unsupportive role of government with Participant AR.36 describing the situation as follows, “If I have to produce my electricity then I am going to look for the most efficient way of producing it […] I can just go down the road and buy a generator or have one fabricated for me”. The challenge identified by the participants highlights the acceptance of the burden of self-power generation as the natural process; the norm, understanding its ins and outs which offers assurance, as well as the somewhat ease and comfort in acquiring generators, regardless of cost. In general, it points to the stability that fossil-fuelled generators provide, which has seen its entrenchment in everyday life, and as such, it has become institutionalised and accepted as the norm.

5.5 Identity
This category highlights the hereditary/entrenched systems and belief of the unsuitability of sustainability in the country and a lack of systems to support adoption. All participants reported a lack of an enabling environment, such as inadequate financial banking and previous unsuccessful projects as a challenge, with all participants attributing responsibility to the government for either abdicating responsibility or acquiescence of foreign control. Participants AR.36 and FM.13 referred to the unsuccessful inaugural projects as the turning point, with Participant A noting “[…] there has always been the question of reliability and robustness of this alternative power sources […] that is because some of the early projects, that many state governments embarked upon were not properly done […] The government always ran politics”. This highlights the influence that the government can have in creating awareness and influencing the type of discussion around issues. It speaks to the government’s self-interest by creating the appearance of activity, interest and commitment for political gain over public interest and the resultant promulgation of a negative image of alternative sources and sewing deep concern. In addition, Participant SE.25 refers to a lack of interest and appreciation for environmental issues as a challenge, saying: “[…] they have not seen the imminent need and they are not threatened by such problems at the moment […] there is very little sustainability”. This suggests two things, first, a lack of awareness either by willingly or otherwise and as such
not being well informed to act. Alternatively, having an awareness but deciding not to act. Also, having a sense of detachment to climate change as it is not directly felt, and as such, is not something of concern. Participants ME.35 stating: “Nigeria has been burning wood for a very long time”. Thus, implying that the activity has been long-standing, with no consequences. The above comments highlight issues represented by Participant SE.25 and point to somewhat deep-rooted beliefs and practices. Adding to this, Participant FM.13 alludes to the lack of empirical evidence of environmental impacts as an issue, as people are not convinced. However, although this may be the case, Participant AR.36 presents a contracting view describing Nigerians as faddish and willing to copy trends, “[…] this is an environment where people are very fashionable and faddish […] you always need the trendsetters [laughs]. And until you find a trendsetter, a trendsetting client, you may have difficulty starting a trend, but the moment it becomes a trend, you get a lot of offtakes”. This speaks to the way of life and the culture of people as wanting to belong. In general, the excerpts reveal, on the one hand, entrenched beliefs and distrust of foreign influence because of government acquiescence as a challenge. On the other hand, the desire to follow western trends as a motivator.

The categories revealed the significance of contextual (cultural) peculiarities in understanding building practitioner’s perceptions and experiences with investors/clients, the public and peers. Salient points, such as institutionalised mentality, sense of detachment and faddish nature, substantiate the significant role that identity plays in RE adoption and the need to understand its dynamics within the Nigerian context.

6. Conclusion and recommendations

The built environment will continue to have adverse impacts on the natural environment and inhabitants as long as construction continues, and although the adverse impacts may not be fully stopped, they can be mitigated against. This is of importance in the context of developing countries, such as Nigeria, that are going through rapid urbanisation and infrastructural development (du Plessis, 2007). Consequently, it is important to ensure that sustainable practices and RE adoption become indispensable. The purpose of the study was to explore the perceptions and experiences of building practitioners in the adoption of RE in commercial buildings in Nigeria. Thereby laying the foundation and useful basis for further/continued research for theory generation.

The findings revealed the significance of contextual (cultural) peculiarities and the role that identity plays in informing RE adoption, which has been missing in previous studies, as the Nigerian perspective has not been holistically embraced. It also further reveals the human experience and relationship between building practitioners and the environment. Overall, the findings showed a gradual move towards RE adoption, particularly solar photovoltaics (PV), as well as sustainability certification, thus highlighting a level of willingness towards achieving sustainability for decentralised power generation, taking into consideration that the current approach to RE adoption is independent of government incentives. This implies the improved adoption of REs with a more enabling environment, which can be facilitated by enhanced collaboration between government, building professional and professional regulatory agencies, such as setting up joint commissions and advisory boards at both local and national levels with representation from the all relevant parties. This will promote awareness and adoption by reframing the sustainability discuss to one which resonates to the public, professional and corporate entities, effectively inform policy and its implementation and enable improved government support through initiatives and incentives.

Also, setting minimum standards for energy and sustainability requirements both in design, through the National Building Code, and appointment agreements will provide the necessary impetus. The latter is exemplified by the regulatory financial body in Nigeria, with the implementation of sustainable banking principles (Deloitte, 2017), which has seen
the integration of REs in bank buildings, as well as pursuance of sustainability certification. Aiding this can be the establishment of a research body and/or knowledge repository, as well as funding from government agencies which will encourage research and development. The findings from the paper have provided a greater understanding of the issues associated with enhanced promotion and adoption, as well as useful information, which will help in sensitising building stakeholders (public, client/investor and practitioners) and policymakers on the value of RE adoption. It will also aid in informing policy interventions suited to the context.

6.1 Contribution to method
The adoption of GTM has enabled the move beyond the standard descriptive statistics traditionally aligned with construction research (Dainty, 1998; Knight and Ruddock, 2008). The use of descriptive statistics provides a limited perspective of issues; however, the use of GMT provided a platform for in-depth and specific insight for the understanding of social processes in relation to RE adoption in commercial (office) buildings.

From the outset of the study, quality was assured, providing an audit trail as it remained aligned with the fundamental procedures and principles of GTM, which innately imposes checks through its systematic and robust integrated approach (Glaser and Strauss, 1967), from data collection, analysis and management to mitigate against inaccuracies and encourage rigour and validity. The following were crucial to the study to achieve quality during data collection and analysis: review of transcripts of interviews against digitally recorded interview, which ensured closeness with data and guided against inaccuracies and researcher bias; analysis of interviews immediately after the interviews, facilitating the process for further sampling (theoretical) to occur; copiously writing memos during the entire process, which allowed the researcher to capture ideas, make comparisons, generate codes, guide further data collection and enabling the creation of detailed records (audit trail) to explain processes; using constant comparative method to enable the explanation of social processes; review and discussion of analysis with research team and experts. In addition, detailed quotes are presented in the findings, to enable the readers to make their own inferences.

GTM facilitated the process of discovery of information, taking cognisance of its inherent elements and enabling direct access to participants (and areas) to better understand the situation in context, thus reflecting the context of Nigeria in the inquiry, which might have otherwise been missing, thereby enabling the potential for benefits to be realised and the opportunity for lessons learned.

6.2 Implications of findings
RE adoption and sustainability in the broader context is influenced by external and internal factors, which both contribute positively and negatively to its adoption in commercial buildings. Consequently, having an enabling environment will not only encourage adoption, leading to positive environmental effects but a social and economic one as well, as they are intrinsically linked. As the alternative will be continued environmental degradation, as well as implications for the construction industry, especially with rapid population growth and urbanisation in the country, which will mean increased energy demand. In addition to the speed in technological advances around the world, which will leave the industry lagging further and struggling to play catch-up.

Given the inadequacies of legislation and obsolete building codes, which has resulted in the ad-hoc design process and reliance on foreign standards. This poses as potential implications for building practitioners and future practice. The danger is that Nigeria is not only importing products but also practices and processes, which are not well suited and are being applied without consideration of the local context. Although it may appear to meet its needs, the end in this situation does not justify the means.
As these findings were unique to the participating practitioners, further qualitative research adopting a GTM approach could be conducted that considers similar areas of inquiry with a diverse sample of building practitioners, including other building stakeholders. In addition, the findings provided an insight into the need for an in-depth understanding of some issues. As such further research could be considered into issues such as the suitability of the adoption of foreign certification within the Nigerian context, as well as utilising the professional conditions of engagement as a special purpose vehicle for sustainability adoption.

References


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Prospects and restraints of
green roofs for high-rise
buildings in Sri Lanka

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Damithri Gayashini Melagoda

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Abstract

Purpose – Green roofs are acknowledged as a method to substitute greenery washed out by the urbanization. They provide many ecological and sustainable benefits of greenery; reduce the adverse effects of high-rise building constructions. Though this concept is more popular across many countries over the past few decades, still, implementation of this technology in Sri Lanka is new and scant. Hence, the purpose of this paper is to identify and analyze the potential of green roofs in high-rise buildings in Sri Lanka.

Design/methodology/approach – The data collection was conducted through expert interviews and questionnaire survey. Expert interviews were carried out to validate the prospects and restraints identified through literature review to the Sri Lankan context and analyzed using content analysis. Questionnaire survey identified the most significant prospects and restraints using descriptive statistics and paired sample t-test. Purposive sampling was used to select participants.

Findings – Reduction of air pollution, aesthetical appearance, thermal benefits and energy savings, reduction of an urban heat island effect, the addition of points in the green rating system are the top most significant prospects that need to be highlighted in promoting green roof systems in Sri Lankan high rises. Less space allocation on rooftops, lack of technical competence and lack of awareness and research are restraints that need most effective elimination strategies to encourage green roof systems.

Originality/value – The first identified and quantified prospects and restraints for green roof system in Sri Lankan high-rise buildings can be utilized by the government, donors, multi-lateral agencies to promote the sustainable development in Sri Lanka and this knowledge could be used in different scale awareness programs. The value of this paper is such that the paper discusses the links of green roofs with the other facets of sustainability. The new legal reforms and amendments in Sri Lanka could potentially be pending with findings of this study.

Keywords Sustainable construction, Sri Lanka, Green roof, Prospects, High-rise buildings, Restraints

Paper type Research paper

1. Background

The planet is getting saturated every day resulting in more buildings and structures within urban settings (Mansoor et al., 2017). The world’s population has rapidly urbanized over the twentieth century; it rose dramatically from 0.73bn in 1950 to 1.51bn in 1975 with an average annual rate of change of 2.91 percent and to 3.42bn in 2009 with an average annual rate of change of 2.4 percent from 1975 to 2009, further predicted to rise to 6.3bn in 2050 (United Nations, 2012). In particular, this growth is predicted to be 93 percent in developing nations with 80 percent growth occurring in Asia and Africa (Martine and Population Fund, 2007). Urbanization brings positive impacts to people and negative impacts on the environment (Estoque and Murayama, 2014). One major environmental problem caused by a rapid and not well-planned urbanization is the decrease of vegetation cover in urban regions due to the expansions of impervious surfaces such as building, parking lots, pavements and other constructions (Ranagalage et al., 2017). Similarly, the ownership of land per person is decreasing in most developing cities with a rapid increase in the value of lands (Halwatura, 2013). High-rise buildings emerged as a solution to cooperate with the supply of space for the population in urban settings with the demand. However, major adverse effects of high-rise building on the environment (i.e. greenhouse gas emission, waste generation, water pollution, water spills, high consumption of
resources, impacts associated with transportation and effects on biodiversity) are identified (Gangolells et al., 2009).

Buildings are responsible for 40 percent of the total world annual energy consumption (Kamarulzaman et al., 2014). The upsurge of energy consumption causing global warming has attracted the serious attention of researchers, architects, engineers, property developers, facilities managers and authorities suggesting green construction concept as a solution for sustainable development (Sheweka and Mohamed, 2012). Conversion of impervious surfaces in urban areas into a multifunctional land cover such as vegetated roofs or green roofs is one of the most effective strategies to mitigate the negative impacts of urbanization (Carter and Butler, 2008). This technology is more popular across Europe and East Asia over the past few decades in countries such as Switzerland, France, Hong Kong (Zhang et al., 2012), UK (Oberndorfer et al., 2007), Portland (Townshend and Duggie, 2007), USA of America, Canada, Australia, Singapore and Japan (Vijayaraghavan, 2016). In contrast, the implementation of this technology in developing countries is still novel and meager (Blank et al., 2013). Therefore, the aim of this study was to identify and to analyze the potential for a green roof to high-rise buildings in Sri Lanka.

2. Literature review
   2.1 Green roof
   Growth is inevitable; a multifaceted and scalable solution is needed to control and reduce the environmental impacts of growing cities; increasingly, developers, architects and city planners recognize that green roofs can be a part of the solution (Clark et al., 2008). There are many descriptors for green roofs, including intensive/extensive living roofs, garden roofs, eco-roofs, vegetated rooftops and high-maintenance/low-maintenance roofs (Barreiro, 2012). The usage of a green roof can be described as the utilization of unused roof space of a building to create green space (Saligheh et al., 2011). As mentioned by Kingsbury and Dunnett (2004), green roof is a planted roof that consists of vegetation and growing medium.

   A green roof comprises a waterproofing membrane, a root constraint, drainage layer, filter layer, substrate and plants. A waterproofing membrane acts as an insulation to prevent moisture from entering the building which sits immediately on top of the structural roof deck (Vijayaraghavan, 2016). Typically, a root constraint layer is designed to prevent roots from penetrating the waterproofing membrane and the structural roof (Bianchini and Hewage, 2012). The next component which protects the waterproofing membrane as well as improves thermal properties of green roof is the drainage layer (Townshend and Duggie, 2007). Filter layer separates the growth substrate from the drainage layer and prevents small media particles from entering and clogging the drainage layer below. The next components are substrate and plants. Green roof substrates need to be lightweight, physically and chemically stable, hold adequate amounts of water and nutrients for plant survival (Rowe et al., 2006). A green roof uses plants ranging from grasses, mosses, lichens, sedums, trees, shrubs, creepers and bushes (Weiler and Scholz-Barth, 2009).

   According to Velazquez (2005), combining plants with architecture is not a new idea, and neither is a green roof. Planting vegetation at the building rooftop is an old technique (Vijayaraghavan, 2016). The earliest documented roof gardens were the hanging gardens of Semiramis (now known as Syria), considered one of the seven wonders of the ancient world (Oberndorfer et al., 2007). Thus, green roof retrofit has emerged after centuries as a new area of practice for building owners and other stakeholders due to arising concerns in green construction (Wilkinson et al., 2015).

   2.2 Green roof in global context
   A green roof is becoming popular in the construction industry due to the upsurge in environment concerns. Köhler and Keeley (2005) mentioned that in some countries,
construction law requires the construction of green roofs in many urban centers. Germany began to encourage new constructions to include greenery as part of the building structure and this made way to the modern-day green roof (Barreiro, 2012). Though, Germany is considered as the world leader in promoting green roof technologies, where over 10 percent of houses installed green roofs. Green roofs became common in other European countries such as France and Switzerland (Zhang et al., 2012). As a result of the regulations for new and renovated flat roofs, 15 percent of conventional roofs in Switzerland have been greened (Townshend and Duggie, 2007).

In Portland, several incentive programs are launched by the government to encourage the construction of green roofs on buildings (Liu and Baskaran, 2005). The government required all new city-owned buildings in Portland to be built with a green roof that covers at least 70 percent of the roof (Townshend and Duggie, 2007). Given their commonly recognized benefits, in 2009, the city of Toronto adopted the Green Roof By-law, which requires the construction of vegetated roofs on 20–60 percent of the roof area in all new developments with a gross floor area of or greater than 2,000 m² (Chen, 2013). Given this policy, from 2010 to 2015, over 196,000 m² of green roofs have been constructed in Toronto (Berardi, 2016). Furthermore, Hong Kong Government is promoting green roofs since 2001 and recently many projects have applied extensive green roofs in Hong Kong mainly in government buildings and public buildings such as schools (Zhang et al., 2012). Similarly, Tokyo (Japan) accelerated the green roofing process by mandating that all new-construction buildings should have green roofs. Private buildings larger than 1,000 m² and public buildings larger than 250 m² must green 20 percent of the rooftop or pay an annual penalty of US$2,000 (Chen, 2013). These figures show that the green roof technology is being adopted by many developed and developing countries in the world.

2.3 Green roof in Sri Lankan context

The urbanization trend is already visible in Sri Lanka (Halwatura, 2013); Colombo and suburbs report highest population density of 3,438 per square kilometer (Department of Census and Statistics, 2012). The temperature and humidity are high throughout the year creating an uncomfortable thermal environment, which, however, would be worse without the afternoon sea breeze in Colombo and suburbs (Emmanuel et al., 2007). Urbanization leads to rapid constructions, which use low albedo materials leading to high heat absorption in urban centers. In addition, removal of vegetation cover and emissions of waste heat from various sources contribute to the accumulation of heat energy, leading to the formation of urban heat islands (UHIs) (Senanayake et al., 2013). Green roofs can decrease the UHIs by a considerable magnitude by increasing vegetation and surface reflectivity (Jaffal et al., 2012). As a result, construction stakeholders are allowing for green roof systems mostly in residential high-rise buildings in Sri Lanka (Heendeniya et al., 2016). Kandalama Hotel is an example for buildings with green roof in Sri Lanka. It has an extensive inaccessible green roof over 465 m² area (Greenroofs.com, 2019).

2.4 Benefits of green roof system

A green roof, known as living rooftops, can be cost-effective as they reduce the energy consumption of buildings for cooling and heating, decrease surface temperatures in cities, prevent storm water runoff from carrying pollutants to surface waters and provide more other benefits (Moghbel and Salim, 2017). In addition to their ecological characteristics, a green roof can improve the life of the roof and provides a fully functioning roof (Kamarulzaman et al., 2014). Although the green roof is initially more expensive to construct than a conventional roof, they can be more economical over the life span of the roof for the reason that energy saved and long life of roof membranes (Porsche and Köhler, 2003).
Moreover, they act positively upon global warming, weather of the city and its region and the interior indoor environment of the buildings beneath them.

Several authors highlighted many economic and environmental benefits which act as opportunities for adopting green roof retrofit. Identified benefits with authors are tabulated in Table I.

2.5 Restraints of green roof system
There is a lot of discussion in the research literature on different benefits and challenges of green roof systems (Williams et al., 2010). Even though research reports and environmentalists attempt to highlight positive aspects of the green roofs, several factors hinder the growth of green roofs as well (Vijayaraghavan, 2016). To improve comparative benefits and bring about advocated green change, researchers need to answer and find solutions regarding the constraints and challenges related to usage and acceptance of green roof (Williams et al., 2010). Emphasized drawbacks with corresponding authors are tabulated in Table II.

3. Methodology
Research approaches are classified mainly into two as quantitative and qualitative (Fellows and Liu, 2015). This study uses both quantitative and qualitative approaches by adopting expert interviews and questionnaire surveys. Purposive sampling was used for sample selection, as green concepts are still in the emerging stage in Sri Lanka, it is needed to identify the correct professionals who have involved in green projects, who have expertise knowledge in green techniques and who are members of Green Building Council, Sri Lanka.

The main aim of the expert interviews was to gather the opinion on the applicability of green roofs in high-rise buildings in Sri Lanka, filter prospects and restraints in implementing green roofs in Sri Lankan context out of the factors identified from the literature and further to collect additional factors. Eights respondents were consulted including architects (two), engineers (two), facility managers (two) and green consultants (two). Except for Green Consultants, all other experts were experienced more than 10 years. Hence, Green Consultants had more than five years of experience as green construction is comparatively a novel field in Sri Lanka. Data collected from expert interviews were analyzed using manual content analysis. The factors which are accepted by four or more than four respondents are carried forward to the questionnaire survey. The questionnaire survey was conducted to analyze the significance of carried forward prospects and restraints from literature and expert opinion survey for future implementation of green roofs. Each identified prospect and restraint is assigned a score based on a one to five points Likert scale (1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree). The respondents were invited to mark the relative significance of each restraint which hinder and prospect which motivate the implementation of green roof systems. In total, 38 professionals participated in the questionnaire survey. All of them are familiar with green concepts and green roofing. Above 70 percent of the respondents had more than five years post-qualification experience. Respondents profile consisted of architects, engineers, quantity surveyors and facility managers engaged in public, private and academic sectors. Data received from the questionnaire survey were analyzed using SPSS Statistics.

Prospects and restraints were compared over each other using paired t-test. The paired sample t-test can determine whether there is a statistically significant mean difference between two sample means with a same number of observations at 95% confidence level when population parameters (variance and mean) are unknown. The main advantage is it can determine whether there is a statistically significant difference between means of samples which displayed skewed t-distribution. Sureshchandar et al. (2012) used paired
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This study measured respondents’ opinions in Likert scale giving them five choices for each of attributes. As indicated by Pallant (2001), Cronbach’s \( \alpha \) value – a commonly used indicator to internal consistency was further calculated using SPSS to measure the reliability levels of prospects and restraints scaled in the questionnaire survey.

Finally, an expert interview was conducted to identify measures to overcome the restraints and improve the prospects identified by questionnaire survey.

4. Analysis and findings

4.1 Findings of expert interviews

All experts agreed that green roofs are applicable in Sri Lanka and seven of them agreed on the applicability in high-rise buildings. A facility manager stated that green roofs are not suitable for high-rise buildings as the rooftop area is mostly occupied by building services such as chiller plants, cooling towers, telecommunication antennas and swimming pools. Thus, he mentioned that green roofs are applicable in low rise buildings. Experts who agreed on applicability of green roofs in high-rise buildings gave their opinions on opportunities and constraints for green roofs in the Sri Lankan context.

From the literature review, eight factors were identified as prospects. Through the expert interviews, additional three factors were identified which are “biodiversity,” “increased roof life and property value” and “better Indoor Environmental Quality (IEQ) and well-being of people.” Furthermore, 12 restraints were identified through a literature review. Experts identified 11 factors as significant to Sri Lankan context and rejected “lack of plants” as a restraint. According to experts, there are a variety of plants available in Sri Lanka as it is within the Top 25 hotspots of biodiversity in the world. It is mentioned that there are 3,368 species of flowering plants and 413 ferns in Sri Lanka (Ministry of Environment and Natural Resources, 1998). But lack of professional experts to advise on the selection of suitable plants according to the type of green roof, location and climate conditions were highlighted.

By scrutinizing the discussions and explanations of the experts, out of the final 12 factors 10 were carried forward for questionnaire survey. Two factors which are technical competence and lack of human resources were merged. Finalized prospects and restraints are summarized in Table III with related coding to be used in questionnaire survey analysis.

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<thead>
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<td>P1 Reduce air pollution</td>
<td>R1 Cost</td>
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<td>P2 Aesthetical appearance</td>
<td>R2 Lack of awareness and research</td>
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<td>P3 Thermal benefits and energy savings</td>
<td>R3 High amount of maintenance</td>
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<td>P4 Reduce urban heat island effect</td>
<td>R4 Lack of support from government</td>
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<td>P5 Points on green rating system</td>
<td>R5 Lack of support from building owners</td>
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<td>P6 Better indoor environmental quality (IEQ) and well-being of people</td>
<td>R6 Lack of technical competence</td>
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<td>P7 Biodiversity</td>
<td>R7 Less space allocation on rooftops</td>
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<td>P8 Noise reduction</td>
<td>R8 Concern on disposal of green roof components</td>
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<td>P9 Increases the roof life span and value of the property</td>
<td>R9 Lack of green roof materials and suppliers</td>
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<td>P10 Storm water management</td>
<td>R10 Uncertainty and risks</td>
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<td>P11 Better run-off water quality</td>
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Table III. Summarized prospects and restraints
4.2 Findings of questionnaire survey
First, the respondents have inquired whether green roofs are applicable to high-rise buildings in Sri Lanka; all 38 respondents agreed (100 percent) that green roofs are applicable to Sri Lanka while only 34 (89 percent) out of the 38 respondents agreed upon the applicability to high-rise buildings. Those 34 respondents were then requested to comment on the significance of each listed prospect and restraint according to the given Likert scale. According to the reliability analysis of prospects and restraints, each scored 0.903 and 0.956 of Cronbach’s $\alpha$ value, respectively. As both of them are higher than 0.6 prospects and restraints can be considered reliable for further analysis (Hair et al., 1998). Mean, standard deviation and skewness of the values given for each factor are tabulated in Table IV. “N” denotes the number of values in the data set.

The statistical mean refers to the average that is used to derive the central tendency of the data set. In this study, the neutral value in the Likert scale used for data collection is three; which implies the respondent neither agrees nor disagrees on the significance of the factor to implement green roofs in high-rise buildings in Sri Lanka. From identified prospect, only “better runoff water quality” (P11) has obtained a mean less than the neutral value. Accordingly, its significance as a prospect on a green roof in high-rise buildings in Sri Lanka can be neglected. Similarly, “lack of green roof material and suppliers” (R9) has obtained a mean less than 3; thus, it can be identified as less significant as a restraint in this study. As a result, “better runoff water quality” and “lack of green roof material and suppliers” are eliminated in paired $t$-test.

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Table IV. Descriptive statistics of factor values
The standard deviation is a statistic that measures the dispersion of a data set relative to its mean. Basically, a minor standard deviation means that the values in the data set are close to the mean of the data set and a large standard deviation means that the values in the data set are farther away from the mean. P11 has got the highest dispersion of values from the mean in prospects while “concern on disposal of green roof components” (R8) is highest in restraints. Skewness is the asymmetry in a statistical distribution. If the bulk of the data is at the left and the right tail is longer, the distribution is said to be skewed right or positively skewed; if the peak is toward the right and the left tail is longer, it is skewed left or negatively skewed. In this data set, six prospects are negatively skewed and others are positively skewed. Only, “lack of support from building owners” (R5) is symmetrically distributed; skewness value is 0, all other restraints are negatively skewed.

Subsequently, the filtered set of data is analyzed using paired \( t \)-test. Results are shown in Table V. The values logged are the difference of means between prospects and restraints (mean value of prospect minus mean value of restraint).

The results present both positive values and negative values. Positive values express that mean of the given significance of the restraint is less than the mean of the significance of the prospect. According to respondents, by giving more consideration on prospects which has positive values effect of restraints on the application of green roofs in high-rise buildings in Sri Lanka can be diminished. In contrast, the mean of the given significance of restraints is higher than the mean of the significance of prospects in negative results. Therefore, concentrating on those factors will be less effective in promoting green roof application in Sri Lankan high rises.

5. Discussion

Most effective prospect to be considered is “reduce air pollution” (P1). Recently, there have been more discussions related to air pollution, maintaining the air quality in urban areas in Sri Lanka. Due to the urbanization, space for plants is lessening; therefore, as the main source of air cleaning, the contribution from plants is difficult to be gained. Roofs are one of the possible places to incorporate plants into the built environment helping to purified the air and absorb polluting particulates (Getter and Rowe, 2006). Plants reduce the negative impact of carbon dioxide and produce oxygen. Plants also help filter out airborne pollutants and help fight against respiratory disease and breathing difficulties. Hence, contribution to reducing air pollution can be considered as the most influential prospect for green roofs in urban high rises in Sri Lanka.

Second most effective prospect is “aesthetical appearance” (P2) brought by green roofs. Urban space is reducing day-by-day. Population migrate into urban areas have to adapt to an overcrowded lifestyle which leads to mental stress. To escape from this, there is a tendency to

<table>
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<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
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<td>-1.412</td>
<td>-0.118</td>
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Table V. Results of paired \( t \)-test  
Note: To highlight minus values of mean
design a built environment with higher contemplation to aesthetical appearance. Green roofs can bring this relaxing and eye-catching view to the built environment. This prospect also emerges over restraints to promote green roofs.

“Thermal benefits and energy savings” for buildings (P3), “reduction of UHIs effect” (P4) and “points on green rating system” (P5) are the other prospects which got a higher significance over restraints. The green roof creates a cooler environment and the need for air conditioning is reduced. Furthermore, conventional roofs in tropical areas create problems for the buildings below them such as uprising indoor temperature, increasing energy demand for cooling, reduced indoor thermal comfort, more expenditure on utility bills and rapid corrosion of the roof materials. Similarly, green roofs have more contribution toward reducing UHIs effects as they are on the rooftop (Saligheh et al., 2011).

The green rating system was introduced to motivate the built environment for sustainable development. Buildings with green ratings are admired over others. Therefore, adding points to the green rating are reflected when designing a building; green roof adding points to this rating is another significant prospect for applicability of green roofs in high-rise buildings in Sri Lanka.

Though “better IEQ and well-being of people” (P6), “biodiversity” (P7), “noise reduction” (P8), “increasing the roof life span and value of the property” (P9), “stormwater management” (P10) and “better run-off water quality” (P11) are identified as prospects for implementation of green roofs, their impact over restraints are less. These factors should also be considered with less priority than earlier mentioned factors.

In restraints that demotivate green roofs, “less space allocation on rooftops” (R7) has obtained positive values in paired t-test over most of the prospects. High-rise buildings usually have more problems in promoting green roof as roof space is occupied by electricity generation (solar/wind/tri-generation), chiller plants and cooling towers, communications towers, swimming pool and other building plants. This can only be overcome with proper planning of buildings in the initial stage. In the initial stage, it should be decided whether to allow space for green roofs or give importance to other service areas or other green technologies such as solar power installations.

Second, it is “lack of technical competence” (R6) and “lack of awareness and research” (R2). In Sri Lanka, a green roof is a new concept and general public, building owners and developers have less awareness about green roofs and benefits they can provide. People need to have access to reliable information sources to learn the benefits of green roofs and to analyze their decisions financially. Awareness and education are vital at this initial stage of development. Researchers should focus green roofs as a major area and conduct research studies on how green roofs can improve the UHIs effects, air quality, storm water management and so on. Each of the prospects of green roofs and restraints of green roofs can be further analyzed in detail in the Sri Lankan context. In addition, studies can be carried out on comparative life cycle cost analysis on building with a green roof and without a green roof or framework to evaluate the performance of green roofs.

The concept of green roofs should be educated to the building professionals who can easily understand its technical aspects. Furthermore, professionals who are involved in other sectors such as accounting and management should be educated of the importance of the green roofs by highlighting the adverse effects and environmental conditions of global warming and the benefits of green roofs in financial terms. A simple payback period or life cycle costing analysis can be elaborated on the savings gained from green roofs through a practical example.

Educational programs can be conducted by government authorities to the people to raise awareness on green roofs. Municipal councils or private sector organizations (as their Corporate Social Responsibility) can organize exhibitions, free seminars and provide study materials emphasizing the need for these green concepts. It is easy to make the people
understand these green concepts and the importance of them as people in Sri Lanka is already experiencing the effects of climate change, deforestation, and many other adverse environmental effects. It is just the correct medium and persons (Local for rural areas and foreign experts to educate wealthy crowd) should be selected to educate them and change their attitude. Universities and industries should run programs through seminars, presentations and study tours for high-rise buildings/buildings which have green roofs to raise awareness, support research and training. Green roof retrofit can be included in curriculums of undergraduates and postgraduates related to the construction industry. Similarly, provisions in the technical colleges are needed, so that building contractors have skills to implement green roofs successfully in Sri Lanka.

Moreover, the green roof is novel to Sri Lanka, professional experts who can address the complex construction process and technical difficulties, experienced installers and maintenance staff are lacking. Architects or landscape architects need to have knowledge of green roofs to select the most appropriate system, structural engineers need to have the knowledge to determine the structural elements required to achieve the desired weight loading and install any structural reinforcement needed in a retrofit green roof, horticulturalist need to provide advice on growing substrate and plant applicable for Sri Lanka and maintenance managers with knowledge on maintaining a green roof. Seminars and conferences can be conducted by Sri Lankan Sustainable Energy Authority or Green Building Council of Sri Lanka for the professionals by foreign experts in green technologies or foreign green consultants.

“Cost” (R1), “high amount of maintenance” (R3) and “lack of support from building owners” (R5) are the next factors to be considered. The initial investment including the design, materials, equipment and labor is high and as many building owners concern only about the cost rather than the future benefits or environmental well-being; they think of the green roof as a burden. The initial cost of green roof is higher than a conventional roof due to the professional fees for designing and planning, contractor fees, planning and building permits, demolition or relocation of existing infrastructure on the roof, importing materials and components and addition of specific hard infrastructure elements. The building owners should be clarified by the consultants by highlighting the savings which green roofs can produce over time through a simple method or detailed analysis. The owners should be encouraged to adopt green roofs not only because of the saving but for the environmental benefits.

“Lack of support from the government” (R4) in terms of policies, regulations, promotions, incentives and “uncertainty and risks” (R10) are comparatively less significant factors. The support given from the government is important for the successful implementation of green roofs in Sri Lanka. There are no proper guidelines relating to green roofs in Sri Lanka currently. The Sri Lankan Government or sustainable authorities need to introduce proper policies and guidelines for green roofs. The government should support regulatory bodies such as the Green Building Council to carry out the necessary actions regarding the improvement of green technologies. The government can provide tax benefits or an exemption from certain service fees for adopting green technologies including green roofs. In addition, the government can promote green roof technology by giving awards to the buildings or building owners or facilities managers/ chief engineers who have implemented proper green roofs and achieving better energy savings. Moreover, the government can give provision on the clean development mechanism and the Kyoto protocol. By doing this, building owners will also be motivated to implement green roofs and the high construction cost can be offset by the incentives and the reputation earned. As a first step to promote green roofs, the government can adopt green roofs in new government high-rise constructions. This will motivate private developers consequently.

“Concern on disposal of green roof components” (R8) is the least substantial factor identified. It has momentum over only two prospects of the green roof which are also least substantial compared to other prospects.
6. Conclusion
There are several negative impacts associated with the urbanization and construction of high-rise buildings. Greenery provides several benefits to the environment and reduces the impacts and adverse effects of urbanization and high-rise buildings. This research clearly identified that green roofs are one of the technologies which can be applicable in Sri Lanka as well as in Sri Lankan high-rise buildings. Furthermore, the prospects and restraints of green roofs in the Sri Lankan context were identified and they were analyzed based on the significance over each other.

The most significant prospects over restraints that need extensive promotional strategies to motivate the adoption of green roofs in Sri Lankan high-rise buildings were found to be: reduction of air pollution, aesthetical appearance, thermal benefits and energy savings, reduction of UHIs, effect and points on green rating systems. In contrast, the most substantial restraints where steps have to be taken to eliminate to encourage the adoption of green roofs in Sri Lankan high-rise buildings were as less space allocation on rooftops, lack of technical competence and lack of awareness and research. As mentioned by the experts, to mitigate the effect of these restraints, it is necessary to increase the awareness through encouraging research and development on green roofs, educating and training of professionals on green roof construction. Furthermore, proper government regulation, policies, incentives and promotion should be established in order to confer green roofs in the upcoming high-rise building projects for a sustainable Sri Lanka. More importantly, real estate developers will obtain cost benefits while users may lead to a comfortable lifestyle. In a broader sense, everyone would be benefited by better environmental conditions due to sustainable construction methods. Sri Lanka is a developing country, above-identified prospects, restraints, measures to overcome restraints and improve prospects may also be applicable to other developing countries and countries at the basic stage of applying green roof concepts to high rise buildings.

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Prospects and restraints of green roofs


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Further reading


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Environmental sustainability of facilities management
Analytical hierarchy process (AHP) based model for evaluation
Nimesha Sahani Jayasena, Harshini Mallawaarachchi and Lalith De Silva
Department of Building Economics, University of Moratuwa, Moratuwa, Sri Lanka

Abstract
Purpose – Rapid changes in the environment escalate the requirement of environmental sustainability assessment within built environment. The purpose of this paper is to model the environmental sustainability of facilities management (FM) functions in apparel industry in Sri Lanka.
Design/methodology/approach – A comprehensive literature review was carried out in order to identify the importance of sustainability assessment for FM, sustainable FM functions and their environmental sustainability indicators. Subsequently, a questionnaire survey was carried out to determine a relative weight of the sustainable FM functions and environmental sustainability indicators through the analytical hierarchy process analysis.
Findings – Energy management was identified as the most significant FM function in terms of environmental sustainability in apparel industry with a relative performance of 49.12 per cent. Subsequently, the functions of water management (29.39 per cent), maintenance management (11.98 per cent) and waste management (9.64 per cent) obtained the second, third and fourth ranks while asset management (7.85 per cent) was the function which had the least performance score. Relative weights for the environmental sustainability indicators were also determined.
Research limitations/implications – In respect of the apparel industry, the developed model can be utilised for assessing the environmental sustainability of FM in broader term.
Originality/value – No proper mechanism was found to assess the sustainability of FM in apparel sector since very fewer research studies were focussed on achieving environmental sustainability in different industries. Hence, the assessment of environmental sustainability of FM in apparel industry is an emerging necessity in the present day, which was addressed in this research.

Keywords Sri Lanka, Analytical hierarchy process, Environmental sustainability, Facilities management, Apparel industry, Assessment model

Paper type Research paper

1. Introduction
Sustainability assessment is vital to obtain an overview of the conceptual and practical usage of the concept of sustainability (Hassan and Hassan, 2016; Penzenstadler et al., 2014). Elmualim et al. (2012) stated that the increasing importance of sustainability, wider variety of sustainability issues and drivers influencing, stakeholders with different values, have initiated a requirement on sustainability assessment. Assessing sustainability of facilities management (FM) is vital to consider since it has been identified as a combined approach in maintaining, improving and adjusting the built environment in order to create an environment that strongly supports the core business of an organisation (Atkin and Brooks, 2009; Barrett and Baldry, 2009). Sustainability assessment is a tool to measure the level of sustainability in FM in an organisation for engaging people within organisations for achieving sustainable development goals (Bebbington and Frame, 2003). With the adaptation of businesses to sustainable approaches, facility manager’s role has been expanded to be responsible for the sustainable performance in any industry (Collins and Junghans, 2015). Kocabas et al. (2009) and Guo et al. (2017) identified that apparel industry
contributes highly in environmental pollution by energy consumption, waste generation, water usage, gaseous emissions and by waste water discharge. Therefore, sustainability assessment of FM in apparel sector is an emerging need (Allwood et al., 2008).

In Sri Lanka, FM is currently practicing in hotel sector, hospitality sector, healthcare sector, industrial sector and condominium sector because of its importance (Weddikkara et al., 2016). The involvement of facilities managers may enable environmentally sustainable FM practices in the industry (Manjula et al., 2015). However, no assessment mechanism has been formed to measure the environmental sustainability of FM in apparel sector in Sri Lanka. Thus, the aim of this research is to develop an environmental sustainability assessment model for FM in apparel sector in Sri Lanka through three objectives; to identify environmental sustainability indicators of FM, to evaluate environmental sustainability of FM in apparel industry in Sri Lanka and to develop a computational model for assessing environmental sustainability of FM in apparel industry.

Next section explains literature findings revealed by secondary data on sustainable FM and its assessment in the world.

2. Literature review
2.1. Environmental sustainability assessment of facilities management
Sustainability assessment is defined by Pope et al. (2004) as “a process by which the implications of an initiative on sustainability are evaluated, where the initiative can be a proposed or existing policy, plan, programme, project, piece of legislation, or a current practice or activity” (p.2). Sustainability assessment model is a framework, which can be used to identify the achievement of sustainability objectives within a project (Cavanagh et al., 2003). Sustainability assessment models track sustainability throughout the life cycle of a project (Sala et al., 2015). It is important to measure sustainability to discover the rate of sustainable practices because sustainability reports are being produced at a higher rate. Sustainability assessment guides to quantify the benefits, percentage of sustainability and guides towards sustainable development (Schielhé and Wallin, 2014). Hence, sustainability assessment is vital for any industry in achieving sustainability goals. As mentioned by Islam et al. (2014), a major concern is developing on the implementation of sustainability initiatives in the apparel sector due to the increasing awareness on impacts of sustainability. In the manufacturing industry, environmental management systems are implemented because of the need of environmental sustainability (Johnstone and Labonne, 2008).

FM can make an important contribution for the sustainable challenges in a business (Nielsen et al., 2016). Further to Nielsen et al. (2016), FM profession can act as a main role in sustainable development and green practices, which are important in environmental, social and economic aspects. FM profession is the most suitable profession to review sustainable practices because of the multi-disciplinary nature of the profession, which allows managing the facility requirements (Elmualim et al., 2012; Gluch and Svensson, 2018). Thus, FM can make an important contribution for the sustainability in industry making it more worth for accurate assessment. Various institutions have developed guidelines and models for sustainability assessment, which are useful to communicate with internal and external stakeholders (Dumay et al., 2010; Hiller Connell and Kozar, 2012). United Nations Commission on Sustainable Development developed a model to evaluate sustainability and divided the core indicators of sustainability into four categories as social, environmental, economic and as institutional (Labuschagne et al., 2007). To measure the sustainability of the operations in industries, Institution of Chemical Engineers has also published a sustainability matrix, where the indicators have being divided into three categories as environmental indicators, social indicators and economic indicators (Singh et al., 2012). Global Reporting Initiative (GRI, 2011) uses a framework in social, economic and
environmental focussed areas in sustainability assessment. However, assigning weights for sustainability indicators has not been given much attention though they are important to broaden the scope of sustainability assessment (Chandratilake and Dias, 2013).

For organisational success in environmental sustainability, performance measurement of FM is important because, FM leads to add value for the organisation through effectiveness and efficiency. According to Tertiary Education Facilities Management Association (TEFMA, 2004), an understanding of the organisational sustainability can be taken through the sustainability assessment of FM because, FM professionals have the ability to considerably effect on the sustainability outcomes in a wide range of activities.

2.2. Environmental sustainability indicators of FM

The sustainable FM functions which were reviewed in the key literature are presented in Table I.

Accordingly, the FM functions, which showed a high frequency of availability in the key literature, such as energy management, water management, waste management, asset management and maintenance management were considered in this research to assess the environmental sustainability. Indoor environmental quality management was considered under the maintenance management as the relationship identified by Kwon et al. (2011). Sustainable purchasing function is being considered in asset management and maintenance management according to Barney (2012).

Environmental sustainability indicators of the selected sustainable FM function were reviewed through an extensive literature review and the findings are presented in Table II. The environmental sustainability of the above selected FM functions was then modelled. The methodology adopted is presented accordingly.

3. Research method

The research was designed to achieve objectives mentioned at Section 1. Literature review was conducted on the major areas of sustainable FM, environmental sustainability and sustainable assessment to appraise the existing methodologies and to identify sustainability indicators as the basis for this research. The survey method was adopted in quantitative phenomena because the research problem requires an objective evaluation. Naoum (2013) stated that the quantitative approach is an objective, fact-finding process based on clear evidence and records. According to Dawson (2007), qualitative approach is

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<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>Maintenance management</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Sustainable purchasing</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
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<td>x</td>
<td>x</td>
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<tr>
<td>Disaster management</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<table>
<thead>
<tr>
<th>Environmental sustainability indicators</th>
<th>Source of reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A  Energy management</strong></td>
<td></td>
</tr>
<tr>
<td>A1 Energy sub-metering</td>
<td></td>
</tr>
<tr>
<td>A2 Usage of renewable energy sources</td>
<td></td>
</tr>
<tr>
<td>A3 Applicability of energy audit results</td>
<td></td>
</tr>
<tr>
<td>A4 Availability of referred/standards for energy efficiency</td>
<td></td>
</tr>
<tr>
<td>A5 Application of energy efficiency targets</td>
<td></td>
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<tr>
<td>A6 Application of advance technologies over energy management</td>
<td></td>
</tr>
<tr>
<td><strong>B  Water management</strong></td>
<td></td>
</tr>
<tr>
<td>B1 Following efficient water fitting standards</td>
<td></td>
</tr>
<tr>
<td>B2 Conducting water audit and application of audit results</td>
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<tr>
<td>B3 Availability of as-built drawings of water distribution</td>
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<td>B4 Availability of a baseline for water consumption</td>
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<tr>
<td>B5 Availability of water sub-metering and data evaluations</td>
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<tr>
<td>B6 Usage of sustainable water resources</td>
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</tr>
<tr>
<td>B7 Availability of water reusing and recycling techniques</td>
<td></td>
</tr>
<tr>
<td><strong>C  Waste management</strong></td>
<td></td>
</tr>
<tr>
<td>C1 Availability of waste management policy</td>
<td></td>
</tr>
<tr>
<td>C2 Properly identified end disposal methods</td>
<td></td>
</tr>
<tr>
<td>C3 Life cycle analysis process availability</td>
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<tr>
<td>C4 Availability of a green purchasing policy</td>
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<tr>
<td>C5 Conducting waste audits</td>
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<td>C6 Applications of reusing waste</td>
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<tr>
<td>C7 Applications of waste recycling</td>
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<tr>
<td><strong>D  Asset management</strong></td>
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<td>D1 Availability of environmental impact assessment for the assets</td>
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<tr>
<td>D2 Availability of green purchasing policy</td>
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<tr>
<td>D3 Availability of supply chain survey before purchasing</td>
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<tr>
<td>D4 Availability and application of performance monitoring system</td>
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<tr>
<td>D5 Application of proper GHG emissions management process</td>
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<tr>
<td>D6 Checking the environmental legal comply of each asset</td>
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<tr>
<td>D7 Extent of green building concept applications</td>
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(continued)
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<tbody>
<tr>
<td>E1 Availability of facility maintenance and renovations policy</td>
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<td>E2 Materials handling and packaging sustainable measures availability</td>
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<tr>
<td>E3 Application of proper GHG emissions management</td>
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<td>E4 Availability of maintenance management practices</td>
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<tr>
<td>E5 Application of chemical management concept</td>
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<tr>
<td>E6 Job related training on environment sustainability</td>
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<tr>
<td>E7 Following international standards in maintenance</td>
<td></td>
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</tr>
</tbody>
</table>

a subjective process aimed at exploring attitudes, experience and opinions of the participants, thus eliminated.

Under the quantitative approach, a questionnaire survey was conducted to collect the data. A questionnaire facilitates collecting data from large number of respondents over a wide area in a shorter period of time (Mathers et al., 2007). A structured questionnaire was developed for pair-wise comparison of the FM functions and environmental sustainability indicators (refer Table III for the scale used in pair-wise comparison). The relative weights for environmental sustainability indicators were derived by utilising the analytical hierarchy process (AHP) technique. The AHP technique was introduced by Saaty (1971) to solve unstructured problems in different areas of human needs and interest.

In this research, convenience sampling was carried out under non-probability sampling since sample size is not at critical in the AHP analysis, as the small sample even secured with its representativeness (Duke and Aull-Hyde, 2002). Further, the AHP method could not be practical for a questionnaire survey with a respondent sample which is large in number as the great tendency of providing arbitrary answers by the respondent which will be resulting in higher degrees of inconsistency (Wong and Li, 2007). Therefore, the questionnaire survey was carried out for a small sample of professionals in the fields of sustainable development and FM in apparel sector in Sri Lanka. In total, 48 professionals in the aforesaid fields were selected for the questionnaire survey (refer Table IV for profile of respondents). Accordingly, 32 were responded in the process (overall response rate is 67 per cent). In addition to that, expert survey consisting five professionals; i.e. executive – environmental sustainability (8 years), sustainability and compliance manager (11 years), engineer (5 years), facility manager (17 years) and engineer (12 years) was conducted to evaluate the developed computational model.

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>2</td>
<td>Weak or slight</td>
<td>Experience and judgement slightly favour one activity over another</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgement strongly favour one activity over another</td>
</tr>
<tr>
<td>4</td>
<td>Moderate plus</td>
<td>An activity is favoured very strongly over another; its dominance demonstrated in practice</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>The evidence favouring one activity over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>6</td>
<td>Strong plus</td>
<td>A reasonable assumption</td>
</tr>
<tr>
<td>7</td>
<td>Very strong or demonstrated importance</td>
<td>May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities</td>
</tr>
<tr>
<td>8</td>
<td>Very, very strong</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td></td>
</tr>
</tbody>
</table>

Reciprocals of above

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1–1.9</td>
<td>If the activities are very close</td>
<td></td>
</tr>
</tbody>
</table>

Table III. Scale used for pair-wise comparison

Source: Saaty (2008)
The respondents of the questionnaire survey were required to carry out pair-wise comparison of the sustainable FM functions and the environmental sustainability indicators and rate them according to their importance. For the ease of reference, the FM functions were coded as A, B, C, D and E, respectively, for energy management, water management, waste management, asset management and maintenance management.

Collected data were analysed by using the AHP technique. According to Vaidya and Kumar (2006), AHP is one of the most widely used multiple criteria decision-making tools. AHP can be used in planning, selecting a best alternative, resource allocations and in optimizations (Saaty, 2008). According to Wong and Li (2008), the steps of AHP include defining the problem and objective, development of the hierarchy, pair-wise comparison, normalising and consistency calculation. Saaty’s rule of thumb is to accept only judgment matrices with consistency ratio (CR) < 0.1 (Deng et al., 2014).

### 3.1. Pair-wise comparisons

Comparison matrices have been developed based on Saaty’s eigenvector procedure and the priority weights have been calculated. A sample model of the pair-wise comparison matrix was illustrated in Table V. The respondents were directed to compare each sustainable FM function and each environmental sustainability indicator as pairs and to indicate the relative importance in the questionnaire. Average of the ratings given by the respondents from pair-wise comparison given for each sustainable FM function is illustrated by \( W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9 \) and \( W_{10} \) and these are highlighted in the table. The reciprocals of them are given in the rest of the area in Table V. Sum of each column is shown as \( S_1, S_2, S_3, S_4 \) and \( S_5 \).

### 3.2. Normalise the comparison

Normalising the entries is done by dividing the entry by the sum of each column in pair-wise comparison matrices. Performance score (PS) is generated by dividing the row sum from the total sum. Table VI represents the model for normalised comparison matrix for sustainable FM functions.

<table>
<thead>
<tr>
<th>Respondent designation</th>
<th>No. of questionnaires distributed</th>
<th>No. of questionnaires received</th>
<th>Respondent rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assistant Managers in Engineering, Sustainability and Compliance</td>
<td>7</td>
<td>4</td>
<td>57.14</td>
</tr>
<tr>
<td>Senior Executives in Engineering, FM, Sustainability and Compliance</td>
<td>20</td>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td>Executives in Engineering, FM, Sustainability and Compliance</td>
<td>21</td>
<td>16</td>
<td>76.19</td>
</tr>
<tr>
<td>Total</td>
<td>48</td>
<td>32</td>
<td>66.67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sustainable FM functions</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – Energy management</td>
<td>1</td>
<td>( W_1 )</td>
<td>( W_2 )</td>
<td>( W_3 )</td>
<td>( W_4 )</td>
</tr>
<tr>
<td>B – Water management</td>
<td>( 1/W_1 )</td>
<td>1</td>
<td>( W_5 )</td>
<td>( W_6 )</td>
<td>( W_7 )</td>
</tr>
<tr>
<td>C – Waste management</td>
<td>( 1/W_2 )</td>
<td>( 1/W_5 )</td>
<td>1</td>
<td>( W_8 )</td>
<td>( W_9 )</td>
</tr>
<tr>
<td>D – Asset management</td>
<td>( 1/W_3 )</td>
<td>( 1/W_6 )</td>
<td>( 1/W_8 )</td>
<td>1</td>
<td>( W_{10} )</td>
</tr>
<tr>
<td>E – Maintenance management</td>
<td>( 1/W_4 )</td>
<td>( 1/W_7 )</td>
<td>( 1/W_9 )</td>
<td>( 1/W_{10} )</td>
<td>1</td>
</tr>
<tr>
<td>Sum</td>
<td>( S_1 )</td>
<td>( S_2 )</td>
<td>( S_3 )</td>
<td>( S_4 )</td>
<td>( S_5 )</td>
</tr>
</tbody>
</table>

Table V. Pair-wise comparison matrix for sustainable FM functions
FM functions. \(X_1, X_2, X_3, X_4\) and \(X_5\) indicate the sum of each row after normalising.\(\tilde{X}\) represents the total sum of the sum column in Table VI.

### 3.3. Consistency calculation

A measure of consistency is the Consistency Index (CI). From this a CR, \(CR = \frac{CI}{RI}\) is derived, using a Randomized Index (RI) and the average CI for randomly filled matrices (Goepel, 2015). The Steps 1, 2 and 3 of consistency calculation can be described as follows:

- **Step 1**: entries in the pair-wise comparison matrix are multiplied by \(PS\) to obtain the eigenvector. \(Z\) is a new vector obtained through addition of each row. Table VI illustrates the normalised comparison matrix and the consistency matrix used in analysis.

- **Step 2**: \(\lambda_{\max}\) is calculated using the equation presented below. \(\lambda_{\max}\) is the average value of the column sum.

The equation used is presented below:

\[
\lambda_{\max} = \frac{a_1 + a_2 + a_3 + a_4 + a_5}{5},
\]

where, \(a = \text{sum}\).

- **Step 3**: CI and CR were calculated as per the Equations (2) and (3), respectively:

\[
CI = \frac{\lambda_{\max} - n}{n-1},
\]  

\[
CR = \frac{CI}{RI}
\]

Further, Saaty’s rule of thumb can be used to accept only judgment matrices with CR < 0.1 (Deng et al., 2014). Random CI is presented in Figure 1.

The general approach of AHP is a two-faced, pair-wise comparison scheme that results in each criterion having a weight and each decision alternative being scored on each of the criteria. Each decision alternative then gets an overall score, computed as the weighted average of its criterion scores (Ehrhardt and Tullar, 2008). Accordingly, overall \(PS\) of each indicator was calculated to assess the environmental sustainability of FM in apparel industry.

### Table VI: Normalised comparison matrix and consistency calculation for sustainable FM functions

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Sum</th>
<th>Performance score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(1/s_1)</td>
<td>(w_1/s_2)</td>
<td>(w_2/s_3)</td>
<td>(w_3/s_4)</td>
<td>(w_4/s_5)</td>
<td>(X_1)</td>
<td>(x_1/X = y_1)</td>
</tr>
<tr>
<td>B</td>
<td>((1/w_1)/s_1)</td>
<td>(1/s_2)</td>
<td>(w_2/s_3)</td>
<td>(w_3/s_4)</td>
<td>(w_4/s_5)</td>
<td>(X_2)</td>
<td>(x_2/X = y_2)</td>
</tr>
<tr>
<td>C</td>
<td>((1/w_2)/s_1)</td>
<td>((1/w_3)/s_2)</td>
<td>(1/s_3)</td>
<td>(w_3/s_4)</td>
<td>(w_4/s_5)</td>
<td>(X_3)</td>
<td>(x_3/X = y_3)</td>
</tr>
<tr>
<td>D</td>
<td>((1/w_3)/s_1)</td>
<td>((1/w_2)/s_2)</td>
<td>((1/w_3)/s_3)</td>
<td>(1/s_4)</td>
<td>(w_10/s_5)</td>
<td>(X_4)</td>
<td>(x_4/X = y_4)</td>
</tr>
<tr>
<td>E</td>
<td>((1/w_4)/s_1)</td>
<td>((1/w_2)/s_2)</td>
<td>((1/w_3)/s_3)</td>
<td>((1/w_10)/s_4)</td>
<td>(1/s_5)</td>
<td>(X_5)</td>
<td>(x_5/X = y_5)</td>
</tr>
</tbody>
</table>

**Notes:** A – Energy Management; B – Water Management; C – Waste Management; D – Asset Management; E – Maintenance Management

The general approach of AHP is a two-faced, pair-wise comparison scheme that results in each criterion having a weight and each decision alternative being scored on each of the criteria. Each decision alternative then gets an overall score, computed as the weighted average of its criterion scores (Ehrhardt and Tullar, 2008). Accordingly, overall \(PS\) of each indicator was calculated to assess the environmental sustainability of FM in apparel industry.
4. Results and discussion

The SFM functions and related sustainability indicators were analysed by using the AHP criteria. Pair-wise comparison, its normalisation and CR were calculated for each and every FM function. Tables VII and VIII illustrate the sample calculations of pair-wise comparison, normalised comparison and consistency matrices for the function of energy management.

As the key findings derived through AHP analysis, the relative performance of each environmental sustainability indicator was calculated as shown in Table IX. Through the calculated PSs, environmental sustainability of the apparel industry can be evaluated. As per the PS calculated, energy management obtained a high PS than other functions (PS = 0.4912). Water and maintenance management obtained second and third rankings

<table>
<thead>
<tr>
<th>n</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3.1946</td>
<td>1.4396</td>
<td>1.5901</td>
<td>0.9646</td>
<td>1.8603</td>
</tr>
<tr>
<td>2</td>
<td>0.3130</td>
<td>1</td>
<td>2.6196</td>
<td>4.1791</td>
<td>0.8413</td>
<td>2.2946</td>
</tr>
<tr>
<td>3</td>
<td>0.6959</td>
<td>0.3817</td>
<td>1</td>
<td>3.0065</td>
<td>0.8132</td>
<td>2.8428</td>
</tr>
<tr>
<td>4</td>
<td>0.6288</td>
<td>0.2392</td>
<td>0.3326</td>
<td>1</td>
<td>1.1397</td>
<td>2.2970</td>
</tr>
<tr>
<td>5</td>
<td>1.0366</td>
<td>1.2292</td>
<td>1.2295</td>
<td>0.8773</td>
<td>1</td>
<td>1.7138</td>
</tr>
<tr>
<td>6</td>
<td>0.5375</td>
<td>0.4357</td>
<td>0.3517</td>
<td>0.4353</td>
<td>0.5834</td>
<td>1</td>
</tr>
<tr>
<td>Sum</td>
<td>4.2119</td>
<td>6.4807</td>
<td>6.9704</td>
<td>11.0885</td>
<td>5.3147</td>
<td>12.0087</td>
</tr>
</tbody>
</table>

Notes: A1 – energy sub-metering and application of submitter reading on identification of significant energy consumers; A2 – usage of renewable energy sources; A3 – applicability of energy audit results; A4 – availability of referred codes and standards for energy efficiency; A5 – application of energy efficiency targets; A6 – application of advanced technologies over energy management

![Figure 1. Random consistency index](image)

Table VII. Example for pair-wise comparison – energy management

<table>
<thead>
<tr>
<th>Normalised comparison – energy management</th>
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</thead>
<tbody>
<tr>
<td>A1</td>
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</tr>
<tr>
<td>A1</td>
</tr>
<tr>
<td>A2</td>
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<tr>
<td>A3</td>
</tr>
<tr>
<td>A4</td>
</tr>
<tr>
<td>A5</td>
</tr>
<tr>
<td>A6</td>
</tr>
</tbody>
</table>

Consistency calculation – energy management

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>Sum</th>
<th>Performance score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.2360</td>
<td>0.7057</td>
<td>0.2463</td>
<td>0.1934</td>
<td>0.1643</td>
<td>0.1480</td>
<td>1.6939</td>
</tr>
<tr>
<td>A2</td>
<td>0.0739</td>
<td>0.2209</td>
<td>0.4490</td>
<td>0.5083</td>
<td>0.1385</td>
<td>0.1826</td>
<td>1.5734</td>
</tr>
<tr>
<td>A3</td>
<td>0.1642</td>
<td>0.0843</td>
<td>0.1714</td>
<td>0.3657</td>
<td>0.1385</td>
<td>0.2263</td>
<td>1.1506</td>
</tr>
<tr>
<td>A4</td>
<td>0.1484</td>
<td>0.0528</td>
<td>0.0570</td>
<td>0.1216</td>
<td>0.1941</td>
<td>0.1828</td>
<td>0.7570</td>
</tr>
<tr>
<td>A5</td>
<td>0.2446</td>
<td>0.2715</td>
<td>0.0570</td>
<td>0.1067</td>
<td>0.1703</td>
<td>0.1364</td>
<td>0.9868</td>
</tr>
<tr>
<td>A6</td>
<td>0.1268</td>
<td>0.0662</td>
<td>0.0602</td>
<td>0.0529</td>
<td>0.0994</td>
<td>0.0796</td>
<td>0.5154</td>
</tr>
</tbody>
</table>

Notes: A1 – energy sub-metering and application of submitter reading on identification of significant energy consumers; A2 – usage of renewable energy sources; A3 – applicability of energy audit results; A4 – availability of referred codes and standards for energy efficiency; A5 – application of energy efficiency targets; A6 – application of advanced technologies over energy management

Table VIII. Example for normalised comparison and consistency calculation – energy management

<table>
<thead>
<tr>
<th>RI</th>
<th>0.00</th>
<th>0.00</th>
<th>0.52</th>
<th>0.89</th>
<th>1.11</th>
<th>1.25</th>
<th>1.35</th>
<th>1.40</th>
<th>1.45</th>
<th>1.49</th>
</tr>
</thead>
</table>

Source: Saaty (2008)
with the PS of 0.2139 and 0.1198, respectively. Kailas et al. (2012) also stated that energy management has obtained greater concern sustainability assessments, such as LEED and other green rating certification systems. In the category of energy management, the highest PS was achieved by ‘energy sub-metering (PS = 0.2360) while usage of renewable energy sources was the second (PS = 0.2209). It is further verified by Efthymiou and Kalogridis (2010) in their study that the identification of energy consumption in different zones is the most important requirement for energy management. Application of advanced technologies over energy management was the least important indicator in energy management (PS = 0.0796).

Conducting water audit and application of audit results (PS = 0.2179) and following efficient water fitting standards (PS = 0.1627) obtained first and second rankings while availability of water reusing and recycling techniques (PS = 0.0940) was the least indicator

<table>
<thead>
<tr>
<th>Code</th>
<th>Environmental sustainability indicators</th>
<th>Performance score</th>
</tr>
</thead>
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<tr>
<td>A</td>
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</tr>
<tr>
<td>A1</td>
<td>Energy sub-metering</td>
<td>0.2360</td>
</tr>
<tr>
<td>A2</td>
<td>Usage of renewable energy sources</td>
<td>0.2209</td>
</tr>
<tr>
<td>A3</td>
<td>Applicability of energy audit results</td>
<td>0.1714</td>
</tr>
<tr>
<td>A4</td>
<td>Application of energy efficiency targets</td>
<td>0.1704</td>
</tr>
<tr>
<td>A5</td>
<td>Availability of referred codes and standards for energy efficiency</td>
<td>0.1216</td>
</tr>
<tr>
<td>A6</td>
<td>Application of advanced technologies over energy management</td>
<td>0.0796</td>
</tr>
<tr>
<td>B</td>
<td>Water management</td>
<td>0.2139</td>
</tr>
<tr>
<td>B1</td>
<td>Conducting water audit and application of audit results</td>
<td>0.2179</td>
</tr>
<tr>
<td>B2</td>
<td>Following efficient water fitting standards</td>
<td>0.1627</td>
</tr>
<tr>
<td>B3</td>
<td>Usage of sustainable water resources</td>
<td>0.1377</td>
</tr>
<tr>
<td>B4</td>
<td>Availability of a baseline for water consumption</td>
<td>0.1305</td>
</tr>
<tr>
<td>B5</td>
<td>Availability of water sub-metering and data evaluations</td>
<td>0.1296</td>
</tr>
<tr>
<td>B6</td>
<td>Availability of as-built drawings of water distribution</td>
<td>0.1276</td>
</tr>
<tr>
<td>B7</td>
<td>Availability of water reusing and recycling techniques</td>
<td>0.0940</td>
</tr>
<tr>
<td>C</td>
<td>Maintenance management</td>
<td>0.1198</td>
</tr>
<tr>
<td>C1</td>
<td>Availability of facility maintenance and renovations policy</td>
<td>0.2064</td>
</tr>
<tr>
<td>C2</td>
<td>Availability of maintenance management practices</td>
<td>0.2044</td>
</tr>
<tr>
<td>C3</td>
<td>Materials handling and packaging sustainable measures availability</td>
<td>0.1496</td>
</tr>
<tr>
<td>C4</td>
<td>Application of proper GHG emissions monitoring and management</td>
<td>0.1491</td>
</tr>
<tr>
<td>C5</td>
<td>Job related training on environment sustainability</td>
<td>0.1203</td>
</tr>
<tr>
<td>C6</td>
<td>Application of chemical management concept</td>
<td>0.0977</td>
</tr>
<tr>
<td>C7</td>
<td>Following International Standards in maintenance</td>
<td>0.0705</td>
</tr>
<tr>
<td>D</td>
<td>Waste management</td>
<td>0.0964</td>
</tr>
<tr>
<td>D1</td>
<td>Availability of waste management policy</td>
<td>0.2302</td>
</tr>
<tr>
<td>D2</td>
<td>Life cycle analysis process availability</td>
<td>0.1837</td>
</tr>
<tr>
<td>D3</td>
<td>Properly identified end disposal methods</td>
<td>0.1706</td>
</tr>
<tr>
<td>D4</td>
<td>Availability of a green purchasing policy</td>
<td>0.1524</td>
</tr>
<tr>
<td>D5</td>
<td>Applications of reusing waste</td>
<td>0.1027</td>
</tr>
<tr>
<td>D6</td>
<td>Conducting waste audits</td>
<td>0.0976</td>
</tr>
<tr>
<td>D7</td>
<td>Applications of waste recycling</td>
<td>0.0630</td>
</tr>
<tr>
<td>E</td>
<td>Asset management</td>
<td>0.0785</td>
</tr>
<tr>
<td>E1</td>
<td>Availability of environmental impact assessment for the assets</td>
<td>0.2597</td>
</tr>
<tr>
<td>E2</td>
<td>Availability of green purchasing policy</td>
<td>0.1886</td>
</tr>
<tr>
<td>E3</td>
<td>Application of performance monitoring</td>
<td>0.1313</td>
</tr>
<tr>
<td>E4</td>
<td>Availability of supply chain survey before purchasing</td>
<td>0.1120</td>
</tr>
<tr>
<td>E5</td>
<td>Application of proper GHG emissions management process</td>
<td>0.1103</td>
</tr>
<tr>
<td>E6</td>
<td>Checking the environmental legal comply of each asset</td>
<td>0.1023</td>
</tr>
<tr>
<td>E7</td>
<td>Availability of green building concept applications</td>
<td>0.0957</td>
</tr>
</tbody>
</table>
in water management. It has been proven by Batchelor et al. (2003) stating that water audits form practical recommendations which can be applied in water management. Further, availability of waste management policy (PS = 0.2302), life cycle analysis process availability (PS = 0.1837) and properly identified end disposal methods (PS = 0.1705) obtained first, second and third rankings in waste management. Barr and Gilg (2005) also stated that the policy affects the total waste management procedure. The indicators of availability of facility maintenance and renovations policy (PS = 0.2084) obtained the highest score in maintenance management while availability of preventive and predictive maintenance management practices (PS = 0.2044) and materials handling and packaging sustainable measures availability (0.1496) obtained the second and third rankings. Ilangkumaran and Kumanan (2009) stated the importance of a maintenance policy for a facility because maintenance system plays a key role in achieving organisational sustainability goals. Further, availability of environmental impact assessment for the assets (PS = 0.2597) and availability of green purchasing policy (PS = 0.1886) were the two highest ranked indicators in asset management.

4.1 Computational model development
By considering the overall PS calculation, the percentage of each indicator was calculated. The computational model was developed by adding the said assessment score calculated for each indicator under five SFM functions in apparel industry (assuming that FM in apparel industry consists of energy management, water management, maintenance management, waste management and asset management). The overall assessment score is equal to 100 per cent. The assessment criteria and the assessment scores are presented in Figure 2.

The developed model can be used to evaluate the environmental sustainability of FM. Environmental sustainability percentage of each function can also be identified and according to the results, necessary actions can be taken to improve the environmental sustainability of FM functions in apparel industry.

4.2 Model evaluation and validation
The developed computational model was validated through an expert survey, which was conducted among the sustainability and FM practitioners in the field. In the survey, the performance of the model was assessed and further improvements were recognised. Accordingly, the validity of the assessment criteria, completeness of the assessment model, applicability for apparel sector, clarity of assessment criteria, user-friendliness and responsiveness of the assessment model were evaluated. The results are shown in Table X.

According to the analysis, the validity of the assessment criteria was at satisfactory level with 60 per cent of response while its completeness was also at satisfactory level (60 per cent). Further, 40 per cent agreed that the model is applicable for the apparel industry satisfactorily. User-friendliness is also at outstanding level as agreed by 40 per cent of respondents. However, clarity and responsiveness of the model were required to be further improved as it was at moderate level (40 per cent). As respondents proposed, introducing sub criterions and assessment scores for smooth calculation and for improving clarity of the model were identified. Further, developing the model as a web or information technology-based tool for easy handing and calculation was also recognised as an improvement that can be considered in the next level of the research.

5. Conclusions
Rapid changes in the environment and stakeholder requirements have created a growing concern on the need of achieving environmental sustainability. Sustainable assessment has also become prominent in this agenda assuring the sustainable goals of organisations. FM is a
key profession which can assist sustainable development within any facility. A major concern is developing on the implementation of sustainability initiatives in the apparel sector due to the increasing awareness on impacts of sustainability through its functions. However, assigning weights for the sustainability indicators and broadening the scope of sustainability assessment have not been given much attention. Hence, with aim of developing well-structured criteria for assessing environmental sustainability, the environmental sustainability indicators of FM in apparel industry in Sri Lanka were evaluated and a computational model was developed in this research. Accordingly, the developed model can be used as a firm base to assess the current status and to formulate the strategies for improving environmental sustainability of FM in apparel industry through a comprehensive evaluation.
References


**Further reading**


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Overcoming barriers for building energy efficiency retrofits: insights from hotel retrofits in Sri Lanka

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Department of Building Economics,
University of Moratuwa, Moratuwa, Sri Lanka

Abstract
Purpose – Despite the pressures around the world to retrofit existing buildings to have higher energy performance, still the level of adoption and implementation of Building Energy Efficiency Retrofits (BEER) appear comparatively low. The purpose of this paper is to explore the barriers that affect the successful implementation of BEER in actual project level executions and identify strategies to overcome such barriers.

Design/methodology/approach – In total, two case studies were conducted in selected hotel buildings to explore the barriers that hamper the adoption and implementation of BEER in the local context and in turn identify the strategies to overcome them. Altogether 11 semi-structured interviews were conducted with respondents involved in different phases of these BEER projects. The data were analysed using code-based content analysis.

Findings – Altogether 38 barriers were identified under the three main project phases. Furthermore, the study revealed 77 strategies to overcome the identified barriers, classified as individual, organisational and national level strategies.

Originality/value – This paper has made a unique contribution to the field by identifying the barriers in each phase of BEER projects and proposing strategies to be taken at different levels to overcome them. The findings of this study will provide a basis for setting up country-wide and organisation-wide strategies for successfully improving the energy efficiency of existing hotel buildings.

Keywords Case studies, Barriers, Strategies, Existing buildings, Building Energy Efficiency Retrofits (BEER), Hotel buildings

Paper type Research paper

1. Introduction
The significance of improving energy efficiency (EE) of existing buildings through retrofitting has often been highlighted in recent years (Ruparathna et al., 2016). Despite this, still the level of implementation of Building Energy Efficiency Retrofits (BEER) appears comparatively low (Liang et al., 2016). Simply, BEER is aimed at making incremental improvements to the building elements and systems with the primary intention of improving EE and reducing carbon emissions (Liang et al., 2016).

Implementing BEER is often hindered by various barriers faced during the different retrofit project phases (i.e. pre-retrofit, retrofit implementation and post-retrofit phases) (Bertone et al., 2018). It has often been highlighted that addressing the many barriers to EE can create a sound basis for scaling up the adoption of EE itself (Soares et al., 2015). Though a number of previous research studies have focussed on determining the barriers for the adoption and implementation of BEER (refer Section 2), none of these studies have identified the specific barriers relevant to the different project phases. Furthermore, to facilitate the successful adoption and implementation of BEER, these identified barriers should be handled in a proper manner, for which strenuous efforts are necessary. So far only a few studies (refer Bertone et al., 2018; ESMAP, 2014; Lewis and Smith, 2014; Liang et al., 2016; Painuly, 2009; SLSEA, 2016) have made attempts to identify strategies to overcome the

This work was supported by the Senate Research Committee of University of Moratuwa under Grant No. SRC/LT/2018/28.
barriers. Yet, these authors have also failed to establish a link between the proposed strategies and the specific barriers or barrier categories. This paper is therefore aimed at identifying the barriers for the adoption and implementation of each phase of BEER projects and proposing strategies to be adopted to overcome them.

2. The adoption and implementation of BEER: barriers and strategies

New energy initiatives face a number of barriers during their adoption, implementation and operation (Bertone et al., 2018). In the context of energy initiatives, Verbruggen et al. (2010) have defined “barriers” as “man-made factors or attributes of factors”, which can be either intentional or unintentional, that operate throughout a BEER project, and have the potential to prevent or hamper action or impede progress or achievement in the realisation of potentials. According to Shove (1998), the barriers faced by organisations during their BEER initiatives can vary from structural to behavioural barriers. Similarly, other authors (refer Bruce et al., 2015; IEA, 2003; Painuly, 2009; Zuhaib et al., 2017) have also classified barriers in implementing BEER in various ways. Hence, it appears that there is no consensus on a standard classification of BEER barriers. In fact, it could be observed that certain barriers have been classified by different authors under different categories due to the absence of clear-cut demarcation of the “boundaries” of each barrier category. However, based on the review of available literature, it was possible to identify nine categories (i.e. financial, technical, informational, managerial, institutional, behavioural, market, regulatory and social) under which the barriers for the adoption and implementation of BEER could be classified (refer Table I). The boundaries defined in Table I have been used as a basis for classifying the barriers derived through the literature into the aforementioned nine categories. These boundaries have been defined based on the findings of Goodier and Chmutina (2014), Mallaband et al. (2013), Miu et al. (2018) and Weber (1997).

Altogether, 57 barriers for the adoption and implementation of BEER have been identified through the review of literature (refer Table I). The most of barriers identified by previous researchers appear to relate to the managerial and technical aspects. However, according to Painuly (2009), among these identified nine categories, financial, technical, information and institutional are the main barrier categories that hinder the adoption and implementation of BEER. Similarly, Bertone et al. (2018) have also disclosed financial barriers as the most deterrent category of barriers when it comes to implementing BEER. Out of the 57, 11 barriers have been highlighted by different authors (e.g. BASF, 2009; ESMAP, 2014; Goodier and Chmutina, 2014; SEAI, 2015) as the key barriers for the adoption and implementation of BEER. These have been indicated in “italic” text in Table I. These key barriers appear to represent six out of the nine identified barrier categories.

As highlighted by Bertone et al. (2018), identifying and adopting potential strategies to overcome barriers are crucial to accelerate the level of adoption of BEER. By compiling the findings from previous studies (i.e. Bertone et al., 2018; ESMAP, 2014; Lewis and Smith, 2014; Liang et al., 2016; Painuly, 2009; SLSEA, 2016), a list of 23 strategies to promote the adoption and implementation of BEER could be elicited (refer Table II).

As shown in Table II, these identified strategies were found to fall into three levels as individual, organisational and national as have been highlighted by Bertone et al. (2018). The review highlighted developing financing packages and providing incentives for BEER projects as key strategies to accelerate the retrofitting rate of the buildings (ESMAP, 2014; SLSEA, 2016). It was also identified that though conducting educational programmes and training campaigns have been typically overlooked in practice (Bertone et al., 2018), these were critical strategies to enhance the level of adoption of retrofit projects (ESMAP, 2014; Lewis and Smith, 2014; SLSEA, 2016). Similarly, selecting an experienced energy service
<table>
<thead>
<tr>
<th>Description</th>
<th>Financial</th>
<th>Technical</th>
<th>Informational</th>
<th>Managerial</th>
<th>Institutional</th>
<th>Behavioural</th>
<th>Market</th>
<th>Regulatory</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barriers related to financial aspects such as cost</td>
<td>Barriers related to technical aspects</td>
<td>Barriers that hinder the attainment of needed information to successfully proceed with BEER</td>
<td>Barriers within the organisations that hinders the adoption and successful execution of BEER</td>
<td>Barriers caused by the involvement of other institutions (i.e. government, local authorities, tenants, etc.)</td>
<td>Barriers caused by the perceptions and behaviour of the individuals</td>
<td>Barriers that hinder the creations of desired market conditions for acceleration of BEER</td>
<td>Barriers caused due to the aspects in legislations, policies, codes, standards, etc.</td>
<td>Barriers created by the parties affected by the BEER (i.e. users, surrounding communities, etc.)</td>
<td></td>
</tr>
<tr>
<td><strong>Barriers</strong></td>
<td>Lack of knowledge and know-how (Lack of technical knowledge and expertise on BEER technologies/measures and how to deploy them)</td>
<td>Lack of information on energy consumption, energy performance and cost effective investments that can be made to improve EE</td>
<td>Inappropriate project management practices</td>
<td>Split incentives</td>
<td>Reluctance to invest in BEER</td>
<td>Perception of risk or uncertainty</td>
<td>Lack of competent regulatory body</td>
<td>Low level of public awareness and understanding</td>
<td></td>
</tr>
<tr>
<td><strong>Lack of access to finance</strong></td>
<td>Lack of availability and reliability on efficient technologies</td>
<td>Unawareness of federal and state incentives related to EE upgrades</td>
<td>Lack of synergy with managerial goals and incentives in business</td>
<td>Lease structures</td>
<td>Inertia of current practices and attitudes</td>
<td>Market capacity</td>
<td>Lack of comprehensive national energy policy and targets</td>
<td>Social norms in relation to thermal and acoustic comfort, light, air quality</td>
<td></td>
</tr>
<tr>
<td><strong>Lack of incentives</strong></td>
<td>Lack of access to efficient technologies</td>
<td>Lack of transparency about energy costs and usage</td>
<td>Unfavourable administrative conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cultural change</td>
<td></td>
</tr>
<tr>
<td>Lack of explicit financing mechanism and debt constraints</td>
<td>Immature technologies</td>
<td>Building owners’ lack of motivation to connect building performance to a clear business case for EE</td>
<td></td>
<td>Building owners’ lack of motivation to connect building performance to a clear business case for EE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I. Barriers for the adoption and implementation of BEER: literature review findings

Overcoming barriers for BEERs
<table>
<thead>
<tr>
<th>Financial</th>
<th>Technical</th>
<th>Informational</th>
<th>Managerial</th>
<th>Institutional</th>
<th>Behavioural</th>
<th>Market</th>
<th>Regulatory</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects of lock-in</td>
<td>Technological incapability due to lack of adequate experts in the area of EE</td>
<td>Difficult to convince the management to undertake BEER</td>
<td></td>
<td></td>
<td></td>
<td>Market fragmentation</td>
<td>Recent developments in building codes or new regulations</td>
<td>Changing energy policies</td>
</tr>
<tr>
<td>High up-front capital expenses</td>
<td>Difficulties in calculating the payback periods</td>
<td>Building operational and management constraints</td>
<td>Unstructured decision making or limited decision-making frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profit sacrifices or insufficient return on investment</td>
<td>Lack of proper programme design and monitoring expertise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevated payback periods</td>
<td>Lack of predictable roadmap for opportunities</td>
<td>Low versatility for intervention in existing buildings</td>
<td></td>
<td></td>
<td></td>
<td>Lack of coherent green workforce development</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Difficult to evaluate and quantify the benefits of BEER</td>
<td>Communication between parties is tedious and complex</td>
<td>Lack of leadership for BEER projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of inter-operability</td>
<td>Lack of staff training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complexity of technologies</td>
<td>Occupancy type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

company (ESCO) to take the responsibility of planning and implementing the retrofit project has also been recognised as an important approach to avoid many of the barriers for retrofitting (Lewis and Smith, 2014).

Despite the above, a gap still remains as to the link between the barriers or barrier categories and the strategies that could be used to address them. For instance, so far no

<table>
<thead>
<tr>
<th>No.</th>
<th>Strategies</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Individual level strategies</strong></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Conduct in-depth study (i.e. audits) in the facility to obtain a clear-cut idea of the project</td>
<td>Lewis and Smith (2014)</td>
</tr>
<tr>
<td></td>
<td><strong>Organisational level strategies</strong></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Develop and adopt a proper project design method (i.e. robust project design method)</td>
<td>Bertone et al. (2018)</td>
</tr>
<tr>
<td>3.</td>
<td>Hand over the project planning, execution and maintenance to ESCO</td>
<td>Bertone et al. (2018), SLSEA (2016)</td>
</tr>
<tr>
<td>4.</td>
<td>Adopt a smart metering system</td>
<td>SLSEA (2016)</td>
</tr>
<tr>
<td>5.</td>
<td>Install building management systems (BMS)</td>
<td>SLSEA (2016)</td>
</tr>
<tr>
<td>6.</td>
<td>Knowledge transfer from the experts attached to the parent organisation</td>
<td>Lewis and Smith (2014)</td>
</tr>
<tr>
<td>7.</td>
<td>Separation of stakeholder roles (i.e. assign separate tasks for the stakeholders) and re-integration</td>
<td>SLSEA (2016)</td>
</tr>
<tr>
<td>8.</td>
<td>Manage the project using a single third party</td>
<td>Lewis and Smith (2014)</td>
</tr>
<tr>
<td>9.</td>
<td>Adopt an efficient coordination system to establish good coordination among the parties</td>
<td>Liang et al. (2016)</td>
</tr>
<tr>
<td>10.</td>
<td>Communicate appropriate individuals with appropriate information</td>
<td>Bertone et al. (2018), Lewis and Smith (2014)</td>
</tr>
<tr>
<td></td>
<td><strong>National level strategies</strong></td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Conduct information campaigns targeting the local banks to increase their awareness on the opportunities that can be gained through providing funding for energy conservation projects</td>
<td>Painuly (2009)</td>
</tr>
<tr>
<td>14.</td>
<td>Conduct educational programmes, training campaigns, CPDs and large-scale capacity building programmes, to provide the needed education, training, and skills on a routine basis at all levels, and make it mandatory for the respective stakeholders (i.e. stakeholders who generally execute the retrofit projects) to take part in it</td>
<td>Bertone et al. (2018), ESMAP (2014), Lewis and Smith (2014), SLSEA (2016)</td>
</tr>
<tr>
<td>15.</td>
<td>Organise and conduct dissemination activities (i.e. workshops or seminars or knowledge sharing programmes) to share the knowledge and experience on energy conservation, results of BEER projects, lessons learned, etc.</td>
<td>Lewis and Smith (2014), Painuly (2009), SLSEA (2016)</td>
</tr>
<tr>
<td>16.</td>
<td>Develop a certification scheme for the effective accreditation of the individuals/organisations according to their sustainability credentials</td>
<td>Lewis and Smith (2014)</td>
</tr>
<tr>
<td>17.</td>
<td>Promote the demonstration of cost and benefits of different retrofit measures</td>
<td>Lewis and Smith (2014)</td>
</tr>
<tr>
<td>18.</td>
<td>Publish booklets with information on various retrofit measures and their benefits</td>
<td>Lewis and Smith (2014)</td>
</tr>
<tr>
<td>19.</td>
<td>Provide EE awards for the organisations who successfully completes energy retrofit projects</td>
<td>ESMAP (2014)</td>
</tr>
<tr>
<td>20.</td>
<td>Establish an information portal</td>
<td>Lewis and Smith (2014)</td>
</tr>
<tr>
<td>22.</td>
<td>Amend building EE codes</td>
<td>ESMAP (2014)</td>
</tr>
<tr>
<td>23.</td>
<td>Establish minimum energy performance standards</td>
<td>ESMAP (2014)</td>
</tr>
</tbody>
</table>

Table II. Strategies to overcome BEER barriers: literature review findings
efforts have been taken to identify appropriate strategies that can be taken at different levels to avoid or better manage specific types of barriers. Besides, a question still remains as to the suitability of these strategies to a specific context or country (Bertone et al., 2018). This paper addresses this issue by identifying the barriers for the adoption and implementation of each phase of BEER projects and suitable strategies relevant for overcoming these identified barriers through empirical investigation.

3. Research methodology
To achieve the aim of this study, the research employed a case study strategy. Case studies were deemed appropriate given that the study required a holistic in-depth investigation of a real-life phenomenon (Yin, 2009). The need of employing sufficient time in investigating the aspects pertinent to the study led to limiting the study to two cases. The cases were selected from successfully completed BEER projects in Sri Lankan hotel buildings. The reasons for limiting the focus of the study to existing hotel buildings were mainly due to their significant energy consumption (SLEMA, 2009) and the level of saving potential (Karawita and Withanage, 2013) compared to other building types. As per SLEMA (2009), luxury hotels spend as much as 50 per cent of their total expenses on energy and have around 20 per cent saving potential (Karawita and Withanage, 2013).

BEER projects can be categorised as shallow (i.e. adopting low up-front cost measures that are relatively easy to install), medium (i.e. focussing on individual systems to achieve the potential energy savings of each building system) and deep (i.e. focussing on multiple building systems and adopt an integrated design approach) retrofits (see Chunduri, 2014). However, Chunduri (2014) also notes that in practice, hotel buildings rarely undertake deep retrofits due to their operation type. Therefore, the focus of this study was limited to shallow and medium retrofits only. In addition, to help identify suitable strategies to overcome the barriers, it was important to select cases that could be considered as “successful” examples of implemented BEER projects. Hence, while selecting cases, the priority was given to hotels that have received the Sri Lanka National Energy Efficiency Awards for their BEER projects. Furthermore, the selection of cases was limited to recently completed projects (i.e. projects completed within the last five years) to capture the contemporary barriers faced by the organisations.

Semi-structured interviews were conducted with stakeholders involved in the respective cases until the point of data saturation. Altogether 11 respondents were selected based on their level of involvement in the selected projects. The details of the selected cases and respondents are presented in Table III.

Among the selected cases, Case A involved the retrofitting of the air-conditioning system by replacing the existing chillers with vapour absorption chillers and a bio-mass boiler. Even though, they had not carried out a similar retrofit before this, they did possess previous experience with implementing other types of retrofit measures. The need for the present retrofit has been identified as the result of an in-depth study conducted by a team from the hotel’s head office to find the root cause for increased energy consumption. The particular hotel was also very “compact” due to the layout of the land. Hence, it was not possible for Case A to house both the boiler and the vapour absorption chillers on the existing hotel premises. Consequently, a decision was made to utilise the land located directly opposite the hotel, which was also owned by the hotel, for locating these. On the other hand, Case B involved the fine-tuning of building some of the energy systems (refer Table III). For Case B, this was the first ever BEER project adopted, which had led them to focus on EE measures that are relatively easy to implement and less costly (i.e. shallow retrofits). Despite this, Case B had also faced several constraints throughout the project, mainly owing to their lack of prior experience with retrofitting.
Both BEER projects were implemented by in-house teams. However, in Case A a specialist contractor had been hired for system installation due to the in-house employees’ unfamiliarity with installing similar systems. Compared to Case B, Case A involved a larger number of stakeholders owing to its project type (i.e. medium retrofit) and the level of knowledge of the in-house staff. Case A also represented a hotel that belonged to a domestic hotel chain. Hence, stakeholders from both the particular hotel and head office of the hotel chain were involved in the retrofit. Therefore, careful consideration was given to all these aspects in selecting suitable respondents for the semi-structured interviews from each case.

Semi-structured interviews were focussed to identify the barriers the selected cases had faced during each project phase and the respective strategies taken by different parties to overcome them. Qualitative data collected through semi-structured interviews were analysed using code-based content analysis. QSR.NVivo (2011) computer software was used to assist in the data analysis process. A hybrid approach was adopted for code generation during data analysis. Initially, a deductive approach to coding was adopted using a list of priori codes developed based on the barriers identified through the literature. At the same time, an inductive approach was adopted to capture and generate new codes as and when any new barriers were identified through the data. The derived findings are presented in the following section.

4. Findings and discussion

4.1 Barriers for the adoption and implementation of BEER

Case study findings disclosed 38 barriers relevant for the adoption and implementation of each phase of BEER projects in existing hotel buildings (refer Table IV). The identified barriers represent eight out of the nine categories of barriers identified in Table I. Among these derived barriers, 25 barriers seem to be in-line with the barriers compiled from the
### Table IV.
Identified barriers during each phase of BEER

<table>
<thead>
<tr>
<th>No.</th>
<th>Barrier</th>
<th>Pre-retrofit phase</th>
<th>Implementation phase</th>
<th>Post-retrofit phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Case A</td>
<td>Case B</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>High up-front capital expenses</td>
<td>3/7</td>
<td>3/11</td>
<td>0/11</td>
</tr>
<tr>
<td>2</td>
<td>Difficulties in attaining the expected savings</td>
<td>0/11</td>
<td>0/11</td>
<td>0/11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/7</td>
<td>1/11</td>
<td>1/11</td>
</tr>
<tr>
<td>3</td>
<td>Lack of technical knowledge and expertise</td>
<td>2/7</td>
<td>3/4</td>
<td>5/11</td>
</tr>
<tr>
<td>4</td>
<td>Lack of programme design expertise</td>
<td>3/4</td>
<td>3/11</td>
<td>0/11</td>
</tr>
<tr>
<td>5</td>
<td>Lack of a predictable roadmap to identify the opportunities</td>
<td>4/7</td>
<td>4/11</td>
<td>0/11</td>
</tr>
<tr>
<td>6</td>
<td>Difficult to evaluate and quantify the benefits of retrofitting</td>
<td>5/7</td>
<td>5/11</td>
<td>0/11</td>
</tr>
<tr>
<td>7</td>
<td>Lack of access to certain technological platforms or software</td>
<td>0/11</td>
<td>0/11</td>
<td>0/11</td>
</tr>
<tr>
<td>8</td>
<td>Lack of programme monitoring expertise</td>
<td>0/11</td>
<td>0/11</td>
<td>0/11</td>
</tr>
<tr>
<td>9</td>
<td>Non-performance of post occupancy assessment</td>
<td>0/14</td>
<td>0/11</td>
<td>3/4</td>
</tr>
<tr>
<td>10</td>
<td>Lack of information (lack of availability of energy consumption data)</td>
<td>2/7</td>
<td>2/11</td>
<td>0/11</td>
</tr>
<tr>
<td>11</td>
<td>Unawareness of locally available incentives for energy conservation projects</td>
<td>4/7</td>
<td>4/11</td>
<td>0/11</td>
</tr>
<tr>
<td>12</td>
<td>Lack of transparency about energy costs and usage</td>
<td>2/7</td>
<td>3/4</td>
<td>5/11</td>
</tr>
<tr>
<td>13</td>
<td>Lack of accuracy and reliability of available data</td>
<td>1/7</td>
<td>1/11</td>
<td>0/11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/7</td>
<td>1/11</td>
<td>0/11</td>
</tr>
<tr>
<td>14</td>
<td>Poor project management practices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Difficult to convince the top management to undertake BEER</td>
<td>1/7</td>
<td>3/4</td>
<td>4/11</td>
</tr>
<tr>
<td>16</td>
<td>Interruptions to building operations and management</td>
<td>4/7</td>
<td>3/4</td>
<td>6/11</td>
</tr>
<tr>
<td>17</td>
<td>Unsystematic way of making decisions</td>
<td>4/7</td>
<td>4/11</td>
<td>0/11</td>
</tr>
<tr>
<td>18</td>
<td>Inability to accommodate alterations in existing buildings</td>
<td>4/7</td>
<td>4/11</td>
<td>0/11</td>
</tr>
<tr>
<td>19</td>
<td>Difficulties in establishing communication between parties</td>
<td>1/7</td>
<td>1/11</td>
<td>0/11</td>
</tr>
<tr>
<td>20</td>
<td>Lack of leadership for BEER projects</td>
<td>3/7</td>
<td>3/11</td>
<td>0/11</td>
</tr>
<tr>
<td>21</td>
<td>Lack of staff training</td>
<td>0/11</td>
<td>0/11</td>
<td>2/7</td>
</tr>
<tr>
<td>22</td>
<td>Occupancy type of the facility which caused</td>
<td>1/7</td>
<td>1/11</td>
<td>3/7</td>
</tr>
<tr>
<td>23</td>
<td>Lack of proper coordination</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>No.</th>
<th>Barrier</th>
<th>Pre-retrofit phase</th>
<th>Number of respondents</th>
<th>Post-retrofit phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Case A</td>
<td>Case B</td>
<td>Total</td>
</tr>
<tr>
<td>24</td>
<td>Delays in getting the approval from the local authority</td>
<td>0/11</td>
<td>5/7</td>
<td>5/11</td>
</tr>
<tr>
<td>25</td>
<td>Reluctance to invest in BEER</td>
<td>1/7</td>
<td>1/11</td>
<td>0/11</td>
</tr>
<tr>
<td>26</td>
<td>Lack of commitment and engagement to BEER</td>
<td>4/4</td>
<td>4/11</td>
<td>2/4</td>
</tr>
<tr>
<td>27</td>
<td>Difficult to change the attitude of the staff</td>
<td>3/4</td>
<td>3/11</td>
<td>4/4</td>
</tr>
<tr>
<td>28</td>
<td>Negligence of the stakeholders which caused system errors</td>
<td>0/11</td>
<td>3/7</td>
<td>3/11</td>
</tr>
<tr>
<td>29</td>
<td>Intense inter-disciplinary collaboration</td>
<td>2/7</td>
<td>4/7</td>
<td>4/11</td>
</tr>
<tr>
<td>30</td>
<td>Lack of trust and confidence on Energy Service Companies (ESCOs)</td>
<td>2/4</td>
<td>2/11</td>
<td>0/11</td>
</tr>
<tr>
<td>31</td>
<td>Difficulties in finding reliable source of advice</td>
<td>1/4</td>
<td>1/11</td>
<td>0/11</td>
</tr>
<tr>
<td>32</td>
<td>Difficulties in selecting the most suitable supplier</td>
<td>0/11</td>
<td>2/7</td>
<td>2/11</td>
</tr>
<tr>
<td>33</td>
<td>Difficulties in finding certain equipment needed for the implementation</td>
<td>0/11</td>
<td>0/11</td>
<td>0/11</td>
</tr>
<tr>
<td>34</td>
<td>Uncertainty of the availability of the needed resources to run the retrofitted system</td>
<td>0/11</td>
<td>3/4</td>
<td>3/11</td>
</tr>
<tr>
<td>35</td>
<td>Delays in getting the ordered equipment</td>
<td>0/11</td>
<td>3/11</td>
<td>3/11</td>
</tr>
<tr>
<td>36</td>
<td>Low level of public awareness and understanding</td>
<td>1/4</td>
<td>1/11</td>
<td>0/11</td>
</tr>
<tr>
<td>37</td>
<td>Social norms with respect to the thermal and acoustic comfort, light and air quality</td>
<td>0/11</td>
<td>1/7</td>
<td>1/11</td>
</tr>
<tr>
<td>38</td>
<td>Negative perceptions regarding the project</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** *a* Represents the number of respondents under the particular case mentioning the barrier, out of the total number of respondents in each case; *b* denotes the total number of respondents from both cases mentioning the barrier.
literature review (refer Tables I and IV), while 13 were elicited only through case study findings (these have been highlighted in Table IV).

Key findings relating to barriers are presented and further discussed in the following sub-sections.

4.2 Pre-retrofit phase

Pre-retrofit phase is the state prior to the implementation of a retrofit project and includes activities from identification of the need for retrofitting to the determination of most suitable BEER measures. A total of 22 barriers were identified as relevant for this phase. Out of these, 16 barriers were faced by Case A, while Case B had faced 10 barriers. Both cases had faced “lack of technical knowledge and expertise” and “unsystematic way of making decisions” as barriers. These could be attributed to the use of in-house staff by both cases in executing the projects. In addition, “lack of transparency about energy costs and usage” and “difficult to convince the top management to undertake BEER” were the other common barriers faced by both cases despite the type of project (i.e. shallow or medium retrofit) undertaken. It was found that poor record keeping practices had led these two cases to perceive lack of transparency about energy costs and usage as a barrier. This has, in turn, resulted in difficulties in convincing the top management to undertake the particular retrofit project.

It was interesting to note through the analysis that among the 16 barriers faced by Case A during this phase, 12 emerged as barriers specific only to this case. Out of these, “difficult to evaluate and quantify the benefits of retrofitting” was the barrier mentioned by most of the respondents of this case. This could be attributed to the lack of up to date information on cost and benefits of different BEER measures. Due to “inability to accommodate alterations in existing buildings” Case A had to develop the needed support infrastructure for the retrofitted system. This had led them to face another distinctive barrier which was “high up-front capital expenses”. This has been exacerbated by the stakeholders’ “unawareness of locally available incentives for energy conservation projects”. Since this particular BEER project was initially led by a team from the hotel’s head office, “lack of leadership” was also highlighted as a barrier specifically faced by Case A. Besides, the in-house team had faced difficulties in clearly identifying the saving potential at the beginning of the project due to “lack of a predictable roadmap to identify the opportunities”.

Conversely, analysis revealed that Case B had faced a total of six barriers specific to them in this phase, which could mainly be attributed to their lack of previous experience with BEER. In particular, the lack of prior experience with BEER and poor understanding of benefits of retrofitting by the employees of Case B had resulted in a “lack of commitment and engagement to BEER”. This was the main barrier faced by Case B as highlighted by all the respondents.

As both of these cases were led by in-house teams, and there was no involvement of other institutions during this particular phase, no institutional barriers emerged as relevant to this phase of the project.

4.3 Implementation phase

Retrofit implementation phase involves the physical execution of the selected retrofit measures. Altogether 16 barriers were derived as relevant to this phase. Out of these, Case A had faced 13 barriers, while only 6 barriers were faced by Case B. The BEER projects in both Cases A and B had been carried out in hotels with 24/7 operation. This had led both cases to perceive the “occupancy type of the facility” as a barrier that had caused difficulties in properly executing the implementation without interrupting the hotel operations. As both projects had been carried out by in-house teams that did not possess previous experience in successfully carrying out similar projects, both cases had faced a number of common barriers such as “lack of technical knowledge and expertise” and “poor project management.
practices”. These were particularly stressed by all the respondents of Case B for whom this was the first BEER experience. Besides, “difficult to change the attitude of the staff” was another barrier highlighted by all Case B respondents due to their failure to effectively communicate the project objectives and its intended outcomes to staff.

In this phase, Case A had faced ten barriers that were specific to the context of the particular case. Out of these, “delays in getting approval from the local authority” was the barrier highlighted by most of the respondents. As this was a medium retrofit project aimed at entirely retrofitting the existing air-conditioning system, there had been certain “interruptions to building operations and management” of Case A during this phase. Moreover, “lack of proper coordination” and “intense inter-disciplinary collaboration” were other distinctive barriers faced only by Case A due to the involvement of various stakeholders from both head office as well as the particular hotel. In addition, due to the involvement of numerous stakeholders as well as the complex nature of the project, Case A had had to make project decisions in an unsystematic manner. On the other hand, installing a bio-mass boiler in an adjacent land under this project had led to “negative perceptions regarding the project” among the local communities who were mainly residential home owners. These negative perceptions were mainly rooted in a fear towards their personal safety, which could, in turn, be attributed to a “low level of public awareness and understanding” about the project. This had resulted in many public protests causing significant project delays. The attempts made by Case A’s project team to obtain technical assistance from industry institutions like SLSEA had also not been effective. This was due to Case A’s “lack of transparency about energy costs and usage” and the reluctance to share such information with outsiders. “Negligence of the stakeholders which caused system errors” was another distinctive barrier faced by this case due to the handing over of system installations to a specialist contractor. Alternatively, due to in-house staff’s lack of experience in executing similar BEER projects, Case A had faced “difficulties in finding certain equipment and fittings needed for the implementation”.

On the other hand, similar to the pre-retrofit phase, “lack of commitment and engagement to BEER” was again identified as a barrier faced only by Case B in this phase. “Delays in getting the ordered equipment” was another barrier faced only by this case, owing to their lack of attention towards maintaining a good relationship with the supplier.

In brief, in the retrofit implementation phase, no financial barriers and only one technical barrier emerged from the findings. This could be attributed to the fact that the total project cost and most suitable financing options are determined in the pre-retrofit phase and the retrofit implementation phase is mainly concerned with the actual physical implementation of selected BEER measures.

4.4 Post-retrofit phase

Following the successful implementation of selected BEER measures, this post-retrofit phase is aimed at assessing the project outcomes to determine any alterations to be made to the retrofitted system. Altogether, 15 barriers were ascertained, which were applicable to the post-retrofit phase. Out of these, 11 and 5 barriers were encountered by Cases A and B, respectively. Findings revealed since in hotel buildings occupancy patterns tend to change from time to time, these two cases had faced “difficulties in evaluating and quantifying the benefits of retrofitting” to assess the project success. This was highlighted by all the respondents of Case B as they did not have past experience with retrofitting. All the respondents from this case further highlighted that “lack of programme monitoring expertise” was another barrier faced in this phase due to the same reason.

Other than “difficulties in evaluating and quantifying the benefits of retrofitting”, the other barriers faced by Cases A and B during this phase, were specific to the context of each project (refer Table IV). Among the barriers faced by Case A during this phase, “lack of
technical knowledge and expertise” of staff to properly operate the retrofitted system, and local community’s “negative perceptions regarding the project” (i.e. local community’s fear of boiler explosion) were the barriers highlighted by most of the respondents.

It was clear that the majority of the barriers in the post-retrofit phase were technical and managerial barriers (refer Table IV). Despite having no prior experience, Case B had faced a relatively smaller number of barriers compared to Case A. This may be because the case involved the adoption of a shallow retrofit involving retrofit measures that are relatively easy to install.

4.5 Barriers for the adoption and implementation of BEER: discussion of findings

Even though different authors have identified “lack of access to finance” (ESMAP, 2014; Goodier and Chmutina, 2014), “lack of incentives” (ESMAP, 2014) and “elevated payback periods” (BASF, 2009) as key financial barriers to undertake BEER, these did not emerge as barriers for implementing BEER projects in the selected two cases. This could be attributed to various reasons. For instance, in Case A, financial assistance had been obtained from an international funding agency for the particular retrofit. On the other hand, the total project cost of Case B was relatively low making it easier to be internally funded.

Similarly, “unfavourable administrative conditions” (Goodier and Chmutina, 2014) and “diverging priorities” (BASF, 2009) also did not emerge as barriers in the context of the selected cases. This may be due to the positive perceptions held by the top management of both cases towards the promotion of sustainability practices and the associated enhancements to reputation.

Though some regulatory barriers were elicited through the literature review (refer Table I), no such barriers emerged from the case study findings despite the lack of regulatory support for BEER in the local context. This might be due to the practitioners’ narrow view on the impacts that regulatory aspects might have on the adoption and implementation of BEER. Although “lack of transparency about energy costs and usage” and “occupancy type of the facility” have been typically overlooked as barriers for the adoption and implementation of BEER (NREL, 2010), these emerged as significant deterrents for implementing BEER in all three project phases. In addition to these two, “lack of technical knowledge and expertise” and “lack of commitment and engagement to BEER” were also found to be barriers that could significantly influence the proper execution of all three project phases.

4.6 Strategies to overcome barriers for the adoption and implementation of BEER

Through case study findings, 77 strategies to overcome the identified barriers were identified. Bertone et al. (2018) had highlighted the vitality of taking actions at both national and organisational levels to enhance the adoption of BEER. Similarly, the analysis revealed that these derived strategies could be classified into three categories as; individual, organisational and national level strategies. Figures 1 and 2 present these identified strategies that are relevant for overcoming each of the barrier categories identified in Table IV. Out of these 77 identified strategies, the majority (i.e. 54) are new strategies derived only through the case study findings (these have been italicised in Figures 1 and 2) and have not been identified from previous literature. However, the remaining 23 are consistent with the strategies identified through previous literature (refer Table II and Figures 1 and 2).

Individual level strategies. Analysis revealed 16 “individual level strategies” to be taken by parties attached to the particular organisation to overcome 14 different barriers falling under 5 different barrier categories (refer Figure 1).

Findings disclosed that poor project management practices had prevented the key stakeholders of these two cases from planning the project in a proper manner. Due to lack
of technical knowledge and expertise of internal staff with BEERs. In both cases, the chief engineer had monitored the installation works and guided the stakeholders throughout the project. Besides, lack of technical knowledge and expertise of suppliers who were also responsible for system installation in Case A had led to the realisation that the most suitable supplier for a project should be determined based on their previous experience and expertise.

To avoid the implications of unsystematic decision making, the stakeholders of these two cases had decided to map the decisions to be made throughout the project and get the needed consultations from the relevant parties. Due to lack of programme monitoring expertise, in Case B, the chief engineer of the property had conducted periodic checks to ensure that the energy consumption readings were taken by the responsible parties. Occupancy type of the facility was another barrier faced by both cases which had caused difficulties in conducting energy audits, proceeding with installations and assessing the savings from retrofitting. Cooperation and assistance of in-house employees was identified as crucial to overcome these in both cases.

Figure 1. Individual and National level strategies to overcome barriers
Findings further revealed that among the derived individual level strategies, “conducting an in-depth audit in the facility” would be useful in overcoming barriers such as the lack of a predictable roadmap to identify the opportunities, lack of information and lack of accuracy and reliability of available data. Similarly, Lewis and Smith (2014) had highlighted the same strategy as useful in obtaining a clear-cut idea of the project. Alternatively, it was ascertained that by planning the project in a proper manner issues that may arise due to poor project management practices, lack of programme design expertise and occupancy type of the facility could be avoided.

Overall findings disclosed that through the adoption of individual level strategies certain barriers relating to technical, informational, managerial, institutional and market categories could be overcome.

---

**Table: Organisational Level Strategies**

<table>
<thead>
<tr>
<th>Barrier Category</th>
<th>Organisational Level Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial Barriers</td>
<td>Adopt good project management approaches and practices to anticipate possible shortfalls and issues that may occur in a project and act in a timely manner</td>
</tr>
<tr>
<td>Technical Barriers</td>
<td>Knowledge transfer from the experts attached to the parent organisation</td>
</tr>
<tr>
<td>Informational Barriers</td>
<td>Utilise a new space to do the system installations</td>
</tr>
<tr>
<td>Managerial Barriers</td>
<td>Establish good communication with the stakeholders via different medium (i.e. meetings, telephone conversations, e-mails, etc.)</td>
</tr>
<tr>
<td>Institutional Barriers</td>
<td>Assign a person to be responsible to ensure the proper communication with the respective parties</td>
</tr>
<tr>
<td>Behavioural Barriers</td>
<td>Provide hands on experience of the way to operate the retrofitted system by arranging visits to the facilities where such systems are already in the operation</td>
</tr>
<tr>
<td>Market Barriers</td>
<td>Insist the stakeholders to complete their works without causing disturbance to lev/ operation</td>
</tr>
<tr>
<td>Social Barriers</td>
<td>Establish good coordination among the parties</td>
</tr>
</tbody>
</table>

**Figure 2. Organisational level strategies to overcome barriers**
Organisational level strategies. Altogether, 44 “organisational level strategies” to be taken by the respective organisations emerged through the analysis (refer Figure 2). These organisational level strategies were found to be relevant for overcoming 30 of the identified barriers relating to all the eight different barrier categories.

To overcome lack of technical knowledge and expertise, organisations could assign a qualified person to take the project leadership throughout the project and guide the project stakeholders to carry out their tasks. Furthermore, encouraging the employees to take part in energy conservation programmes and requesting the suppliers to do demonstrations on system installations also emerged as strategies that could address this. Moreover, the respondents highlighted that by handing over the project planning, execution and maintenance to a specialist third party such as an ESCO and by making recruitments after assessing the candidate’s experience and abilities to manage the retrofitted system, issues associated with lack of technical knowledge and expertise could be avoided in future. Among these two strategies, the former was highlighted by Bertone et al. (2018) as a strategy to ensure the successful execution of retrofit projects.

Difficulties in evaluating and quantifying the benefits of retrofitting had led both cases to install separate metres for each building system, integrate building systems with BMS and establish and adopt proper M&V protocols. Furthermore, both cases had also used previous data on savings from similar projects to quantify the saving that could be attained from the retrofit. Establishing a proper M&V protocol was also useful in overcoming the difficulties that may arise due to lack of programme monitoring expertise as was revealed in Case B. In addition, it was ascertained that obtaining the assistance of ESCO in doing the M&V, and conducting demonstration programmes to make the employees aware of the ways of properly doing M&V would also be useful in overcoming this barrier.

Installing separate metres or adopting smart metering systems; installing BMS; and establishing good relationships and sharing energy consumption pattern data with organisations capable of providing technical advice were also found as useful strategies to overcome the barrier of lack of transparency about energy costs and usage faced by both cases. This appears to be in-line with the findings of SLSEA (2016), who has stated that adopting smart metering systems and installing BMS could facilitate the quantification of building energy uses and help to identify the building areas/devices with high energy consumption.

To convince the top management to undertake BEER, both cases had conducted meetings with top-level managers of the hotel to provide a clear view on the main opportunities and options available to improve EE. Both cases had also conducted awareness programmes to make the top management aware of the importance of undertaking a BEER project and the potential outcomes. To overcome the difficulties relating to occupancy type of the facility, both cases had installed separate metres for each building systems, transferred knowledge from the experts attached to the parent organisation and assigned separate roles for each stakeholder and re-integrated subsequently. The latter two strategies have also been emphasised by authors like Lewis and Smith (2014) and SLSEA (2016), particularly to avoid complexities associated with BEER projects executed in functioning buildings.

Case B had conducted awareness programmes to gain the necessary commitment and engagement for the project and change the negative attitudes of staff. Such awareness programmes had helped disseminate the project details and its intended outcomes to the staff making them aware of the importance of undertaking the project. In addition, the respondents of this case also divulged that linking the successful completion of the project with employees’ performance assessments and promotions would also assist in overcoming this barrier.
Case A had managed to overcome the local community’s initial negative perceptions towards the project by establishing and maintaining good relationships with the neighbours, and making the public aware that the organisation was keen on protecting the environment and ensuring safe operation of the system.

National level strategies. Findings disclosed 17 “national level strategies” to be taken by government/SLSEA to eliminate 16 barriers relating to 6 different barriers categories (refer Figure 1).

Supporting the findings of Lewis and Smith (2014), analysis revealed that practices, such as disseminating knowledge and experience on energy conservation, results of BEER projects, lessons learned, etc.; promoting the demonstration of cost and benefits of different retrofit measures; and publishing information on various retrofit measures and their benefits, would be useful in properly evaluating and quantifying the benefits of retrofitting.

Findings disclosed that the government can also take several strategies to encourage top management to undertake and gain sufficient commitment for BEER projects. These include providing EE awards for organisations that successfully complete BEER projects, introducing a mandatory energy consumption disclosure policy, and establishing minimum energy performance standards. Besides, providing incentives for energy conservation projects, promoting the demonstration of cost and benefits of different retrofit measures and amending building EE codes would also be beneficial in encouraging top management to undertake BEER. Similarly, authors like ESMAP (2014) and Lewis and Smith (2014) have identified these strategies as drivers to adopt BEER projects (refer Table II). As per ESMAP (2014), both fiscal and monetary incentives such as tax credits, cash rebates, capital subsidies, low interest financing or soft loans, green mortgages, etc. would be useful in encouraging the adoption of BEER. These incentives are specifically found to be useful in relieving the uncertainty of BEER projects by strengthening profits and shortening payback times (Liang et al., 2016). Though encouraging financial institutions to develop innovative financing packages for BEER projects was found to be essential in cutting down the required high up-front capital for retrofit projects, Painuly (2009) had disclosed that the same strategy could also contribute towards scaling up the adoption rate of retrofit projects in the long run.

“Conducting mandatory educational programmes, training campaigns, CPDs and large-scale capacity building programmes” was found to be useful in overcoming barriers such as lack of technical knowledge and expertise, lack of programme design expertise, poor project management practices and lack of staff training. From a similar standpoint, Bertone et al. (2018) and SLSEA (2016) have insisted that this same strategy would provide the industry practitioners with sufficient confidence to undertake and execute BEER projects successfully. Besides, the findings revealed that “developing a certification scheme for the effective accreditation of the individuals or organisations according to their sustainability credentials” would be useful in overcoming lack of trust and confidence on ESCOs and difficulties in finding reliable sources of advice. Similarly, Lewis and Smith (2014) maintained that this particular strategy would also be useful for the practitioners in selecting the suitable parties (i.e. external parties like suppliers, specialist contractor, ESCO, etc.) for the project. As shown in Figure 1, through the adoption of these national level strategies, all types of barriers except institutional and social barriers could be overcome.

As a whole, the analysis disclosed that the adoption of certain strategies would be useful in tackling more than one barrier, which may or may not fall within the same barrier category (refer Section 4.3 and Figures 1 and 2). This highlights how certain barriers for the adoption and implementation of BEER are interrelated, and hence open up an avenue for further investigation.
According to Hussaini and Majid (2015), the barriers for the adoption and implementation of BEER can be overcome by a strong determination and willingness on the part of the government and other relevant stakeholders. The findings of this study also made evident that to tackle the barriers of BEER, efforts are needed from a variety of stakeholders such as project teams, governments and other industry institutions like SLSEA (refer Section 4.3).

5. Conclusions and implications of findings
This study aimed to explore the barriers that could affect the successful project level execution of BEER and identify strategies to overcome such barriers. Through the findings of two cases, a list of 38 barriers for the successful adoption and implementation of BEER were derived under eight categories (refer Table IV). The research suggests that “lack of technical knowledge and expertise”, “lack of transparency about energy costs and usage”, “occupancy type of the facility” (which caused difficulties in conducting audits and properly identifying the energy saving from the retrofitted system) and “lack of commitment and engagement to BEER” are the barriers which had significant impacts during all three retrofit project phases (refer Table IV). The findings also revealed the possibility of encountering commitment issues in all three project phases by organisations that do not have prior experience with retrofitting. Altogether 77 strategies, classified as individual, organisational and national level strategies, that can be adopted to overcome these identified 38 barriers were found (refer Figures 1 and 2). Hence, this study makes a valuable contribution to theory and practice by identifying the linkages between the specific barriers or barrier categories that could be overcome through the adoption of different individual, organisational or national level strategies.

Overall, this paper provides some valuable insights from two retrofit cases to industry practitioners and policy makers on the barriers when pursuing BEER projects particularly in the hotel sector. Although the selected cases were limited to two, the findings of these cases provide an in-depth view of barriers that might be encountered in undertaking these types of retrofits in similar contexts. The findings of this study would facilitate the industry practitioners in understanding the barriers for the adoption and implementation of BEER and finding appropriate strategies to be taken at different levels to avoid or better manage such barriers.

References


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Design toolkits for campus open spaces from post-occupancy evaluations of federal universities in South-west Nigeria

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Abstract

Purpose – Participatory design strategy through post-occupancy evaluation of built assets is a feedback mechanism into the design process. This paper draws upon a wider empirical study that aims at evaluating the University Campus Open Spaces (UCOS) of six federal universities in South-west Nigeria. The purpose of this paper is to generate evidence-based design toolkits for UCOS towards spanning of disconnects between designers and users thereby revisiting and revitalizing their design criteria.

Design/methodology/approach – A sample (n = 3,016) of users was drawn in a cross-sectional survey through stratified random method. The research instrument was a structured questionnaire in multiple choice and Likert-type scales. The data obtained were subjected to statistical techniques.

Findings – Results show that males use the UCOS for active and passive recreation than females. The UCOS are male dominated because the females have higher concerns for lack of safety and inclement weather. Both genders have equal preference for sitting. “Group academic” activities are at peak in the “afternoon”, while “being alone” takes place in the “evening” and “personal academic” in the “morning”.

Safety is primary to zoological and botanical gardens. Social interaction spaces enhance successful recreation parks. Coherence and legibility are the highest cognitive satisfaction factors for pedestrian sidewalks.

Practical implications – The research generated design requirements for UCOS, and it is important for informing better design solutions in the future.

Originality/value – The results are synthesized into three-in-two new frameworks to guide future design actions for innovative strategies between design and use/operational phases.

Keywords University, Campus, Landscapes, Built assets, Design frameworks, Open spaces, Post-occupancy evaluation

Paper type Research paper

Introduction

Design toolkits are intellectual and conceptual frameworks for designing spaces that are human centred (Hanington and Martin, 2012). They are evidence-based set of tools for identifying design requirements and users’ needs for successful architectural deliveries (Forsyth et al., 2017). Design toolkits are not only essential for delivering sustainable university campuses constituted by buildings with open spaces between them; they are sine qua non for revamping university campus-built assets (Aydin and Ter, 2008). Campus-built assets include land and water areas that are not covered by buildings. These areas are termed University Campus Open Spaces (UCOS) in this paper. UCOS include roads, plazas, parking lots, recreation parks, natural green areas and vacant lands. The plants, structural materials and art works on UCOS are referred to as landscape elements. Assessment of UCOS can be carried out through post-occupancy evaluations (POE). POE can aid the development of toolkits as a feedback and feedforward input into the design process (Preiser, 2001).
It is a logical procedure for the assessment of built assets from the perception of users (Syafriny and Sangkertadi, 2010).

Furthermore, POE can help designers to design better UCOS in the future by assessing the performance of existing UCOS in their operational/use phase. Designs are usually carried out by relying on quantitative technical measures and simulation instead of users’ perception. Worst still, designers are generally not fully acquainted with the performance of the spaces during their use phases in different settings (Yang, 2007). This leads to repetition of design mistakes and the spaces are used in manners that are only partly envisaged (Cubukcu and Isitan, 2011), causing a disconnection between designers and users.

Therefore, this study’s concern about users’ perception is guided by some questions:

**RQ1.** How does users’ status influence the use of UCOS in South-west Nigeria?

**RQ2.** How do use and status influence perceptions of qualities?

**RQ3.** What factors underpin users’ satisfaction? What aspects of user satisfaction can inform design of UCOS?

To answer these questions, the research aims to evaluate the UCOS of the six federal universities in South-west Nigeria with a view to evolving design frameworks. Specifically, it identifies the status of the users and assesses their perceptions of qualities. It also analyses the relationship between status of users and their perceptions of qualities. Other objectives are determination of the factors influencing users’ satisfaction and development of design frameworks for UCOS. These offer tangible proof to direct future design decisions (Cubukcu and Isitan, 2011). Therefore, the study presents benefit of the integration of design and operational phases of future built assets for the study area and beyond. It was carried out on the campuses of six federal universities in the six States of South-west Nigeria. The States are Lagos, Ogun, Ondo, Oyo, Ekiti and Osun. The study is framed within the context of this location and situated within a wider literature background on the design of UCOS.

**Literature review**

**University Campus Open Spaces design requirements**

The goal of designs should be targeted towards the need of users and not the job satisfaction of designers for their distinctiveness (Saksa, 2011). The urban nature of university campuses suggests that this goal can only be achieved through participatory modelling (Lefebvre, 1996).

There are two categories of participatory modelling: pre-construction and post-construction. Pre-construction participation is generally called participatory design. It has to do with direct contribution of end users throughout the design process (Schuler and Namioka, 1993). However, it can only be used where the end users are specific during the design phase (Naderi and Shin, 2008). The participation of users after the design phase generally falls under post-construction participatory modelling. This modelling is characteristically called POE.

**Post-occupancy evaluation (POE)**

POE participatory modelling involves all prime stakeholders in the delivery process of a built asset. It has been discovered to be an unsurpassed procedure in landscape decision-making processes and has adequate results (Sandker et al., 2010). Preiser (2002) names three types of POE to include indicative, integrative and diagnostics. Indicative POE provides the clue of strengths and weaknesses. Investigative POE is an in-depth process that gives a rigorous consideration to the causes and effects in performance. Diagnostic POE relates physical and environmental measures with measures of personal responses of occupants to create new
knowledge about aspects of performance (Preiser, 2002). Accordingly, the approach of the present study suggests diagnosis.

POE has been engaged as a tool to assess specific physical design configurations. These configurations may be influential factors in supporting the use of campus spaces (Spooner, 2008). POE can help in the determination of activities, expectations, dissatisfactions and general experience of users in public open spaces (Malkoc and Ozkan, 2010). The experience of users can inform the formulation of design frameworks.

Design frameworks and satisfaction factors for open spaces
A number of frameworks that account for satisfaction (cognitive, social, spatial and affective) and use (purpose, period, mode and hindrance) factors abound in the literature. Few of these frameworks are most relevant to UCOS. These frameworks are identified in this section while readers can get their details in the literature. All the factors are explored in this study unlike the existing frameworks. This is required because Fornara and Troffa (2009) argue that “place experience is a complex pattern which involves affective, cognitive, social and behavioural aspects that interact with the physical features of the places” (p. 2).

Cognitive factors are environmental qualities that influence human perception and preferences (Kaplan and Kaplan, 1982; Tang et al., 2015). The factors are coherence, legibility, complexity and mystery. Coherence means “environments easy to organize or structure”. Legibility implies “environments suggesting they could be explored extensively without getting lost”. Complexity has to do with “environments with enough in the present scene to keep one occupied”. Mystery implies “environments suggesting that, if they are explored further, new information could be acquired” (Kaplan, 1992, p. 587). These factors are the four components of Kaplan and Kaplan (1982) information processing framework of space preference. However, this framework lacks other factors.

Social and use factors are components of socio-ecological framework by Sreetheran and Van Den Bosch (2014). Social factors of environmental satisfaction are socially constructed notions of place attributes that foster social interaction. They include conviviality, visual privacy and others (Thwaites and Simkins, 2006). In this socio-ecological framework, use factors include personal attributes of the user (age, gender, etc) and time (period) of use. However, it does not consider other factors. The other factors are conceptualized in this study as purpose, mode and hindrance to using spaces (Doughty and Lagerqvist, 2016).

Spatial factors are partly components of framework of urban park management (Chan et al., 2015). The framework is limited to parks and gardens. The Place Diagram (Project for Public Spaces, 2000) is another framework. It is limited to socio-spatial considerations including accessibility and others. Affective factors are the components in the Russell and Lanius (1984) model of affective quality of places. The model proposes that emotional reactions to environments can be described by their relative position on unpleasant–pleasant and arousing–not arousing continua. These include beautifulness and others. However, the model lacks consideration for status of users.

Furthermore, the framework for built environment (Sandalack and Uribe, 2010) is another framework. It is a spatial framework and sets out the general character of the built environment. However, it lacks definition of users and their requirements. Also, urban design framework of Carmona et al. (2010) provides only spatial dimensions and underpinning concepts for the design process. The strength of socio-spatial framework for healthy campus open space design developed by Lau et al. (2014) shown in Figure 1 lies in its theoretical underpinning (Ulrich, 1984). It has a major flaw in its designer-oriented approach that excludes users’ voice. Also, the authors acknowledge the inherent weakness of the framework by concluding that the next stage of research have to further
quantitatively examine the collection of design strategies to achieve optimal use of space and create a vigorous, lively and sustainable learning, teaching and research milieu (Lau et al., 2014). Despite the identified weaknesses of this framework, it provides the best approach to understanding the nature of UCOS landscape design since it was developed from a study on campus landscapes. In view of the diverse limitations of these existing frameworks, the study aims at evolving a related set of frameworks as design toolkits.

This review suggests that none of the existing frameworks in the literature includes all the factors that are crucial to understanding the performance of UCOS. Since the frameworks are also developed from different contextual settings, they are not compatible to be fed simultaneously into the design process of UCOS. This gap in the literature informs the pursuit of the present study. Each of the existing frameworks accounts for one or more of use, cognitive, social, spatial and affective satisfaction factors. These are their strengths. However, the existing frameworks are not fully user centric. Also, none of the frameworks account for all use and satisfaction factors holistically and simultaneously within the context of users’ design requirements for all types of UCOS. The strengths have been integrated into the current study by including all the use and satisfaction factors in a single study in the same context of users’ design requirements. It combines all the factors concurrently by aggregating the peculiar strengths of the existing frameworks thereby overcoming their weaknesses and situating them in a single research design.

**Research design**
The study population and geographical spread are wide. In view of this, the sample drawn is extremely large and covers campuses of six universities. For such large population, and because of the need for generalization, Nardi (2018) recommends survey design being

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**Figure 1.** Framework for healthy campus open space design
“less costly to reach larger samples” (p. 20). Monette et al. (2013) propose applied research design when there are specificity and practicality of research concerns as in this case. Chilisa and Kawulich (2012) also suggest the necessity of applied research design when the required data variables and parameters of study are based on critical realist ontology.

Data were collected on the research populations. These comprise of all the open spaces and users on the university campuses. The different groups of users involved in the survey are students, academic and non-academic members of staff. The students have high populations compared with staff members. They are mostly young and active people, both undergraduates and postgraduates, male and female. The staffs are less in population compared with the students. They are mostly middle aged and include both male and female. The coverage area within each campus was restricted to academic and administrative zones. They are the areas that are common to all the categories of users compared with residential areas. The sample size of users that was drawn from the population was determined according to Krejcie and Morgan (1970) table. The required total sample of users was 2,245.

The instrument for collecting quantitative data from the sampled users is a structured questionnaire. It contained 80 close-ended questions. The questions were based on the investigation variables and parameters. This was to enable uniformity and analysis as recommended by Sreejesh et al. (2014). The variables and parameters were sourced from the existing frameworks in the literature. They were organized into three sections. Section 1 contains seven general information as status of users about gender (two categories), discipline (five categories), car ownership (two categories) and impairment status of users (five categories). All these are nominal scale variables. Others are age (four categories), educational status (five categories) and level, for students (six categories) and are ordinal scale variables.

Section 2 contains measurement of perceptions of qualities of 12 types of UCOS. These include zoological and botanical gardens and others. The perceptions of qualities were measured separately for each type of UCOS. The measurements were based on ordinal scale devised as 1 = poor, 2 = scanty, 3 = averagely set, 4 = well set, and 5 = excellent.

Section 3 contains the satisfaction factors in five groups. The first group is uses of the UCOS. In this group, purpose (seven categories), period (six categories), mode (five categories), and hindrances (five categories) were measured on nominal scales. The second group is four cognitive factors including coherence and others. The third group is seven social factors including conviviality and others. The fourth group is seven spatial factors including accessibility and others. The fifth group is 13 affective factors including restfulness and others. Each member of second to fifth groups was measured as ordinal scale variables. The scale was calibrated as 1 = very unsatisfactory, 2 = unsatisfactory, 3 = undecided, 4 = satisfactory and 5 = very satisfactory.

UCOS were categorized according to Stanley et al. (2012) in the instrument design. This categorization was partly adopted by Lau et al. (2014) and improved by Shakibi (2015) by adding sub-categories. Simple stratified random sampling (SSRS) technique was employed for the users. This was because each university campus readily forms stratum (Levy and Lemeshow, 2008). According to Chaudhuri and Stenger (2005), this randomization is required for generalization of results based on probability sampling theory.

Randomization was also carried out during pilot survey towards the standardization and validation of the instrument. In total, 245 (i.e. 10 per cent of sample size as recommended by Simon, 2011) copies of the instrument were administered based on SSRS technique. The instrument was statistically verified for criterion validity and internal consistency (Groves, 1987). All the items on the same scale in the instrument were correlated ($p < 0.05$) and Cronbach’s $\alpha$ value of 0.928 the least for items on the same scale (Cohen and Swerdlik, 2010).
Copies of the standardized instrument (3,016 in number) were administered to obtain the main data. The data obtained were subjected to descriptive and inferential statistical techniques with Statistical Package for the Social Sciences 20.0 version Software. The descriptive techniques include frequencies and percentages because the variables are discrete (nominal and ordinal). Also, because of the categorical/discrete data involved, non-parametric inferential analyses were carried out. \( \chi^2 \) statistic tests were carried out to test the relationships between statuses of users, use' factors and perception of quality (PoQ) of 12 types of UCOS. The goal was to test a null hypothesis that PoQ is not contingent upon use' factors. According to Kothari (2004), a null hypothesis is a statistical proposition on the relationship between two variables that can be put to a test “to determine its validity” (p. 184). The data involved in the \( \chi^2 \) tests are status of users, period, purpose, mode and hindrance. Others are PoQ of zoological and botanical gardens, playgrounds and others. Where significant relationships were established in the \( \chi^2 \) tests, Cramer’s \( V \) Correlation tests were carried out as post hoc to determine the strength of such relationships with effect sizes. This involves the relevant data in the \( \chi^2 \) tests and include gender, mode, hindrance, impairment and discipline.

Spearman’s rank correlations were carried out to determine the relationships between satisfaction factors and PoQ. This is because the data involved are measured in ordinal scale. The data include satisfaction with cognitive, social and spatial factors and PoQ of 12 types of UCOS earlier mentioned. Ordinal regression analyses were carried out to estimate the impacts of satisfaction factors influencing perceptions of qualities. It involves the data for the Spearman’s rank correlations. The data for these two analyses are measured in ordinal scale as required by Kothari (2004). Corder and Foreman (2014) recommend Kruskal–Wallis \( H \)-test to establish if there is any significant difference among variables that are based on location as nominal data. Therefore, the data involved in this test are campuses of six universities as a variable and PoQ of 12 types of UCOS in the campuses. Kruskal–Wallis \( H \) post hoc tests involving these data were carried out where significant differences were discovered. This was to identify where the differences lie through the value of the test statistic for each university. The results of the analyses are presented in the next section.

### Results, findings and discussion

#### Response pattern

A total of 3,016 copies of questionnaires were administered to all the categories of respondents during the main data collection. Out of this number, 2,347 (77.82 per cent) were returned. A total of 1,759 (74.95 per cent) out of the figure returned were found suitable for analysis through data cleaning process recommended by Bohannon et al. (2007). This figure (1,759) represents 78.35 per cent of the calculated minimum sample size of 2,245 (100 per cent). This is within the “very good rate” of 70–85 per cent in landscape assessment face-to-face questionnaire survey research according to Milburn et al. (2003). This suggests that a robust response rate was achieved and results of the analyses are reliable based on the users’ concerns.

#### Statues of users of the campus open spaces

Statues of the users are shown in Table I. There are more males than females. Majority are undergraduate students while few attended only Primary Schools. Most of them are in their active age bracket of 19–45 years while the least are above 65 years of age. Majority does not own cars and do not have physical challenge. Those who are enrolled in the Basic/Applied/Agric Sciences are more, and those in Arts and Commercial are the least. The users represent all categories and are well acquainted with the UCOS. Therefore, their value judgements can be upheld as outcomes of experiences in the uses of the spaces.
Uses of the campus open spaces
Results of the analyses are outcomes of experiences of users. In the results, “group academic” purpose has the highest use being 496 (31.5 per cent). This is followed by “personal meditation”, 411 (26.1 per cent), among others. “Passive recreation”, 10 (0.6 per cent) is the least. “Afternoon (12:00 noon–4:00 p.m.)” users are the highest being 505 (32.3 per cent) and “night (8:00 p.m.–6:00 a.m.)” use, 39 (2.5 per cent) is the lowest. Majority, 541 (34.1 per cent), of the users sits in open spaces. The least, 151 (9.5 per cent), stands among other results. “Unfavourable weather”, 586 (41.2 per cent), constitutes major hindrance to use of the UCOS while “lack of safety”, 137 (9.6 per cent) is the least. The uses are also affected by status of users. “Passive recreation” takes place throughout all periods.

Relationships between status of users and uses of the UCOS
According to Allen (2017), apparently small values of strengths of association (effect sizes) have high implications when the sample size is large. The sample size in this study is large, being 1795. The degrees of freedom (df) are also high, varying between 5 and 30.

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<td>133</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1,759</td>
<td>100</td>
</tr>
<tr>
<td>Physical challenge</td>
<td>None</td>
<td>1,755</td>
<td>99.8</td>
</tr>
<tr>
<td></td>
<td>Blindness</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Walking stick assisted</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Crutches assisted</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Wheel chair assisted</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1,759</td>
<td>100</td>
</tr>
</tbody>
</table>

Table I. Status of users of University Campus Open Spaces in South-west Nigeria

<table>
<thead>
<tr>
<th>Status of users of University Campus Open Spaces in South-west Nigeria</th>
<th>Car ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Status</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>1,095</td>
<td>62.3</td>
</tr>
<tr>
<td>Female</td>
<td>664</td>
<td>37.7</td>
</tr>
<tr>
<td>Total</td>
<td>1,759</td>
<td>100</td>
</tr>
</tbody>
</table>
McGrath and Meyer (2006) propose that, for a df of 5, 0.01–0.04 is a small effect size, 0.05–0.13 is a medium effect size and 0.14–0.22 is a large effect size when the sample is large. The $p$-value shows how likely the association found by the effect size in the samples exists in the study (parent) population. $p$-value is significant at 95 per cent (0.05/0.005) or 99 per cent (0.01/0.001) confidence level. This implies that the chance that the association is due to sampling error is only 5 or 1 per cent, respectively. $p$-value greater than 0.05 shows that the result obtained on that parameter/variable from the sample is not true of the study population and should, therefore, be discarded as recommended by Benjamin et al. (2018).

In view of these statistical decision rules, results show that there is significant difference in the purpose of using the UCOS between males and females (df = 6, $\chi^2 = 18.051$, $p = 0.006 < 0.05$). The effect size of this difference is also high at Cramer’s $V = 0.107$. The modes of pedestrian use of the spaces are significantly different between the genders (df = 5, $\chi^2 = 29.001$, $p = 0.000 < 0.05$) with high effect size (Cramer’s $V = 0.135$). The mode of pedestrian use (df = 10, $\chi^2 = 101.509$, Cramer’s $V = 0.179$, $p = 0.000 < 0.05$) and hindrances to use (df = 8, $\chi^2 = 34.591$, Cramer’s $V = 0.110$, $p = 0.000 < 0.05$) are significantly different among the age groups.

**Relationships between purpose and period of use**

Spearman $\rho$ correlation was carried out on the four uses’ factors to understand the pattern of their relationships. “Common purpose of use” and “common period of use” are highly correlated with a coefficient of 0.936 at 95 per cent confidence level ($p = 0.000 < 0.05$). This implies that particular activities go on in each of the UCOS at peculiar times. The bar chart generated in the analysis and shown in Figure 2 explains the pattern of these relationships. It shows that “group academic” is at its peak in the “afternoon” and “group religious”
activities take place in the “twilight” and “night”. The chart also shows that “being alone” is at its peak in the “evening” and “personal academic” in the “morning”. Others are “utilitarian” in the “dawn” and “active” and “passive recreation” take place in the UCOS throughout all periods but not as pronounced like other uses.

Testing of hypothesis that perceptions of qualities are not contingent upon use' factors

χ² tests were carried out to investigate the null hypothesis that perceptions of qualities are not contingent upon use’ factors. According to the results, hindrances to use affect the PoQ of zoological gardens (df = 16, χ² = 47.852, p = 0.000 < 0.05). However, period (p = 0.421 > 0.05), purpose (p = 0.192 > 0.05) and mode (p = 0.181 > 0.05) of use do not. This result is similar to that of botanical gardens where only hindrances to use (df = 16, χ² = 50.839, p = 0.000 < 0.05) relates with PoQ.

Furthermore, only mode of pedestrian use (p = 0.082 > 0.05) does not have significant impact on the PoQ of plazas/squares. Period (df = 16, χ² = 38.585, p = 0.008 < 0.05), purpose (df = 24, χ² = 45.756, p = 0.005 < 0.05) and hindrances (df = 16, χ² = 42.907, p = 0.000 < 0.05) significantly affect the PoQ of plazas/squares. The general accessibility characteristic of these UCOS may suggest that perceptions of their qualities are reliant on these latter factors. For courtyards, only hindrances to use (df = 16, χ² = 28.050, p = 0.031 < 0.05) significantly affect the PoQ. Period (p = 0.966 > 0.05), purpose (p = 0.860 > 0.05) and mode (p = 0.748 > 0.05) do not. Both mode of use (df = 20, χ² = 37.513, p = 0.010 < 0.05) and hindrances (df = 16, χ² = 41.581, p = 0.000 < 0.05) have significant impact on the PoQ of pedestrian sidewalks. For pedestrian linear corridor, only purpose has significant impact on PoQ (df = 24, χ² = 47.207, p = 0.003 < 0.05). The PoQ of vacant lots is significantly affected by purpose (df = 24, χ² = 49.977, p = 0.001 < 0.05), mode (df = 20, χ² = 34.085, p = 0.026 < 0.05) and hindrance (df = 16, χ² = 28.585, p = 0.027 < 0.05) concurrently.

Intrinsic factors influencing users' satisfaction

Cognitive factors. A Spearman’s rank-order correlation was run to determine the relationship between 1759 users’ satisfaction with four cognitive factors and perceptions of qualities. The strengths of correlations are measured as Spearman’s ρ (rs). The decision rules on the interpretation of p- and ρ-values are the same as earlier explained for Cramer’s V.

All the results obtained indicate high correlations. The minimum ρ is 0.174 and the maximum being 0.400, majority at 0.250 upwards. Very few ρ values are at this lower band and all are significant at 99 per cent (p < 0.000) confidence level. For instance, the correlation results for sports pitch (complexity: rs = 0.355, p = 0.000; coherence: rs = 0.333, p = 0.000; legibility: rs = 0.324, p = 0.000; and mystery: rs = 0.308, p = 0.000, in descending order) and playgrounds (complexity: rs = 0.325, p = 0.000; mystery: rs = 0.323, p = 0.000; coherence: rs = 0.300, p = 0.000; and legibility: rs = 0.294, p = 0.000, in descending order) demonstrate the diversity of the different requirements for various field sports events and varieties of playgrounds for different games. On the whole, higher satisfaction with the cognitive factors informs higher PoQ.

Social factors. Spearman’s rank-order correlation results for zoological gardens show that safety (rs = 0.330, p = 0.000) has the highest correlation coefficient. This is followed by social interaction spaces (rs = 0.312, p = 0.000), the least being open space for personal meditation (rs = 0.252, p = 0.000). Among other results, recreation parks present a departure with social interaction spaces (rs = 0.306, p = 0.000) being the highest. This is followed by open space for personal meditation (rs = 0.289, p = 0.000) and safety (rs = 0.236, p = 0.000) being the least. Sports pitch and playgrounds have similar results with recreation parks. Their social interaction spaces are equally significant to the satisfaction of users. Conviviality (rs = 0.309, p = 0.000) is the second significant satisfaction factor for sports pitch and playgrounds.
Spatial factors. Six spatial satisfaction factors were investigated through Spearman’s correlation. Among other results, convenience \((r_s = 0.314, p = 0.000)\) has the highest coefficient and continuity \((r_s = 0.265, p = 0.000)\) the least for zoological gardens. Invariably, zoological gardens should be designed for convenience to enhance the movement of users from one section to another. However, they are not expected to be at continuity with other UCOS at the main activity areas. Rather, they should be secluded since the proximity correlation coefficient is also low \((r_s = 0.266, p = 0.000)\) compared with others. Among other results, correlation of spatial satisfaction factors with squares/plazas (accessibility: \(r_s = 0.288, p = 0.000\); proximity: \(r_s = 0.217, p = 0.000\); among others) suggests that squares/plazas require all the spatial factors but with gradient of importance for the best PoQ.

Affective factors. The correlation coefficients’ results of affective satisfaction factors for zoological gardens suggest that fascinating-ability \((r_s = 0.346, p = 0.000)\) is the most important. This is followed by pleasantness \((r_s = 0.323, p = 0.000)\) while recuperative-ability \((r_s = 0.294, p = 0.000)\) is the least. Results for botanical gardens is similar to this but beautifulness \((r_s = 0.294, p = 0.000)\) is second to fascinating-ability as satisfaction requirement. The affective satisfaction factors that have the highest correlation coefficient for each UCOS are as follow: conservation areas, beautifulness \((r_s = 0.291, p = 0.000)\); fascinating-ability for recreation parks \((r_s = 0.319, p = 0.000)\), sports pitch \((r_s = 0.340, p = 0.000)\) and playgrounds \((r_s = 0.336, p = 0.000)\).

Influence of satisfaction factors on perceptions of quality

Ordinal regression analysis was carried out to estimate the impacts of satisfaction factors influencing perceptions of qualities. The results in the model for each UCOS indicate that as the ratings of the satisfaction factors increase, the PoQ increases. Each overall model is significant at 99 per cent confidence level as shown in Table II.

Comparison of responses among the six federal universities

Kruskal–Wallis \(H\) and post hoc tests were carried out to identify the pattern of the statistically significant differences in the responses among the six universities. A pairwise customized analysis result shows that all the UCOS are perceived to be of different qualities in most cases, except few. For instance, result shows that there was a statistically significant difference in the PoQ of zoological and botanical gardens among the universities with \(\chi^2(\text{df}, 5) = 531.927, p = 0.000 < 0.05\) and \(\chi^2(\text{df}, 5) = 332.577, p = 0.000 < 0.05\), respectively. Post hoc tests reveal that the university located in Oyo State has the best perceived zoological and botanical gardens with test statistics of 1,207.46 and 1,105.19, respectively. The two gardens are perceived to be of least qualities in the university located in Ekiti State with test statistics of 309.97 and 361.86, respectively. This confirms observations that the university located in Oyo State has the first zoological and botanical gardens in the study area.

Design frameworks for University Campus Open Spaces

The findings of the study are synthesized into three-in-two design frameworks patterned after Lau et al. (2014). They are integrated into the frameworks in Figures 3 and 4 by linking the variables, parameters and factors in the study discovered to be related since the study is designed as a correlation research (Kothari, 2004).

Composite use-purpose-period framework. Figure 3 shows a composite use-purpose-period framework, developed from the findings of the study. According to these outcomes shown in Component “A”, the use-user’ status sub-framework indicates that gender of user determines the purpose and mode of use for which design provisions should be made. Also, age classification determines outdoor furniture requirements for different modes of use.
Component “B” shows the proposed purpose-period-mode sub-framework. According to the outcomes of the study, the framework indicates that personal academic, group academic, meditation/being alone and group religious use require sitting facilities for both males and females for different activities. Specifically, it stresses the requirement for group religious activities at twilight and night.

Spaces-satisfaction factors’ framework. Figure 4 shows the spaces-satisfaction factors’ framework. It contains 12 types of UCOS and 5 groups of satisfaction factors according to the research design. Since the research design is correlational, the UCOS that correlated with specific satisfaction factors in the outcomes are linked together. This concept is adapted from Lau et al. (2014). According to the outcomes of the study, the framework indicates that coherence is the most general cognitive design requirement for all the types of UCOS. Therefore, complex recreation parks can be coherent and enhance wayfinding behaviour, being legible.

Social interaction spaces are required in the design of recreation parks, sports pitch and others. Convenience of use is a major design requirement for zoological and botanical gardens, recreation parks and others. Safety concerns are crucial to the location and design of zoological and botanical gardens and conservation areas. Courtyards should be connected to indoor spaces and be made convivial by including facilities for snacks where users can also socialize. Pedestrian linear corridors require proximity, among other functional requirements. Recreation parks allow multiple uses/purposes while mode of use should be considered for conservation areas.
Unlike these proposed frameworks, the limitations of each of the existing frameworks show in incorporating different strands of use and satisfaction factors while lacking in others. These have been overcome in the proposed new frameworks by incorporating all the factors.

**Recommendations and conclusions**

The study discovers that males use the UCOS for active and passive recreation than females. The UCOS are male dominated because the females have higher concerns for lack of safety and inclement weather. Both genders have equal preference for sitting. “Group academic” is at its peak in the “afternoon” and “group religious” in the “night”. The higher
the age and academic level of a user, the higher the required design provisions. Specific UCOS were perceived to be of better quality on each campus.

Safety is a primary satisfaction factor for zoological and botanical gardens. Social interaction spaces are central to successful recreation parks, sports pitch and playgrounds need to be convivial. Coherence and legibility are by far the highest cognitive satisfaction factors for pedestrian sidewalks than for any other UCOS.

Furthermore, UCOS should be designed for pleasurable strolling. Period of use is significant to designing for various uses at different hours. Social interaction spaces and convenience of use should be integrated into the design of recreation parks, sports pitch, playgrounds, plazas/squares and all other civic open spaces. Safety concerns should be built into the location and design of zoological and botanical gardens and conservation areas. Courtyards should be connected to indoor spaces and made convivial. Recreation parks should be designed to allow for multiple uses/purposes and mode of use should be considered for conservation areas as indicated in the proposed frameworks.

None of the existing frameworks holistically and simultaneously account for use, cognitive, social, spatial and affective satisfaction factors for all typologies of UCOS. The existing frameworks are also not fully user centric. These limitations have been overcome in the proposed frameworks. They account for all use and satisfaction factors holistically and simultaneously within the context of users’ design requirements for all types of UCOS.

The findings of the study are synthesized into a new set of comprehensive frameworks for the design of UCOS. This is an original contribution to the body of knowledge that details the parameters for understanding and measuring the performance of UCOS. These findings can be applied in practice by engaging the frameworks for brief analysis towards programme development at the design stage. Thus, the frameworks are detailed design requirements and how they are interrelated. They are recommended as design toolkits as feedback and feedforward input into the design process for innovative strategies between design and use/operational phases. They promise to boost and optimize the life-cycle sustainability of campus-built assets. Directions for further works include studies on design considerations for maintenance and management involving design professionals and horticultural considerations on materials and installations.
References


Design toolkits for campus open spaces


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