Improving maintenance management practices on green building projects

Zul-Atfi Ismail
Civil Engineering Program,
School of Environmental Engineering, Universiti Malaysia Perlis, Arau, Malaysia

Received 1 May 2019
Revised 26 July 2019
Accepted 11 November 2019

Abstract

Purpose – The improper maintenance affects the performance of management practices for Green Building (GB) in Malaysia. This is due to the issues of lack of GB knowledge and competency for maintenance activities in GB projects. However, only a few researchers have investigated maintenance within the GBs. This may be due to industry's lack of awareness concerning the currently existing maintenance problems and their causes. The paper aims to discuss these issues.
Design/methodology/approach – This paper intends to develop a new Information and Communication Technology (ICT) based approach for managing maintenance in GB schemes. As a precursor to this work, the current maintenance management activities, ICT tools and techniques are reviewed and explored in such projects to gather processes and information database of maintenance and management.
Findings – The findings reveal the need for more sophisticated maintenance management solutions that accord with the needs of GB schemes to manage quality and reduce associated defects.
Originality/value – The paper concludes by presenting a research framework for developing such a system in the future. It is also suggested that further research into maintenance of GB should consider issues in terms of concern for lifecycle assessment and sustainability.

Keywords Framework, ICT, Project, Maintenance management, Green building, Improper maintenance
Paper type Technical paper

1. Introduction

As more commercial organisations have sought to develop green building (GB), building owners and occupiers have been interested in understanding the return on investment; which could get through the benefits associated with building "green" rather than met its costs of maintenance operation (Ravindu *et al.*, 2015). It is not surprising that companies of any size presenting their GB service focus on lack of GB maintenance for integrating green measures into their maintenance plans. It is, therefore, necessary to devise appropriate policies on a GB maintenance adoption in specific projects in order to derive strategies for improvement where necessary. Many maintenance companies for GB aim to provide environmental sustainability through pure engineering and design efforts (e.g. electricity, water and materials) as valuable as possible in order to meet a client's needs (Thatcher and Milner, 2016). GB maintenance involves the critical and unique heating, ventilation and air conditioning (HVAC) components and on-site renewable energy systems installation that utilise techniques, products, components or infrastructure systems from the structural classification (e.g. glass walls and water treatment equipment (softeners, filtering systems)) and need critical maintenance contractor attention towards their specialisation services delivery for energy and water use reporting on GB. In general, GB is assessed and certified by the rating systems of respective countries such as Leadership in Energy and Environmental Design (LEED) is practiced in the USA, which is structured into two phases: the first phase is the assessment on the design of the building (DA) and the second phase is known as the Completion and Verification Assessment. In Malaysia, GB assessment tools have been undertaken in order to acquire the level of Green Building Index (GBI) certification

This article forms part of a special section "The micro-foundations of management of environmental quality", guest edited by Sanjay Kumar.

Management of Environmental Quality: An International Journal
Vol. 31 No. 4, 2020
pp. 803-817

1477-7835
DOI 10.1108/MEQ-05-2019-0093

program based on the efficient utilisation for energy in buildings. GBI is developed and established by Pertubuhan Arkitek Malaysia and The Association of Consulting Engineers Malaysia that intend to classify the best-in-class GB strategies and practices. They started from silver level for the basis of green principles and project specifications towards gold or platinum levels when more sophisticated and unproven technologies are applied to become highly committed to energy efficiency (Mohammad *et al.*, 2014).

Presently, the current approach for decision support tools such as manually Computerised Maintenance Management System (CMMS) on inspection process is not as effective as it could be in achieving the required quality and operational requirements (Azari and Kim, 2016). Besides, it is often inconvenient to imitate preventive maintenance measures, legislation protection or GB designation standard and work procedures onto GB construction sites to detect the conflicts and problems that can be resolved before the design process. Consequently, the GB maintenance personnel have an information deficit to visualise any subsequent conflicts, for instance the work-related building restoration activities during the real-time building maintenance (Aktas and Ozorhon, 2015). The manually CMMS also affects the delay of delivery information for the as-built condition at the GB construction site (Gan *et al.*, 2015). The CMMS has to be reviewed for the coordination and revision; also, management solutions should be created for the architect and contractor for communicating the GB building maintenance information (Ferwati *et al.*, 2019). In addition, the Information and Communication Technology (ICT) application has not been totally applied to facilitate the manager, engineer and other key personnel in gaining the information access to the computer database system from the concerned GB building construction sites. The inefficiency of on-site queries also may cause downtime, repetition of work, waste and cost over-runs. Therefore, the existing tools need to be improved for the process of information delivery from the particular GB facility through the computer-generated model. The model approach should have the major advancement to produce CMMS that contains the precise geometry and relevant data needed to support the durability of GB buildings, thus resulting in prioritising execution needs, rehabilitation and maintenance performance (Ulubeyli and Kazanci, 2018).

This paper is structured as follows: the first section presents the current maintenance management practices in GB construction projects and the common problems. The second section is focused on assessing the reasons of maintenance management issue and making constructive approaches for improving it. Finally, the main conclusions and future work are presented to discuss some of the application that Information and Communications Technology (ICT) use to support smart GB management and the framework for the sophisticated GB building system solutions.

2. Methodology

The literature review was conducted for searching the existing literature on GB maintenance management processes in construction industry. Besides, the maintenance management issues were reviewed to identify the weaknesses of the current practice concerning GB maintenance management system. The paper also reviewed the implementation of ICT and information system to support the maintenance management, especially on data and analysis at GB projects. Based on the studies conducted on the implementation of information system in construction industry, it can be observed that there are some major difficulties of the features system that impact the maintenance monitoring, retrieving and waste control in the respective organisations. The mentioned systems provide the GB inspection functions in order to facilitate staff in completing the assessment report. However, the information access is not fully comprehensive diagnostics. The building diagnosis has fault detection problems to identify the detailing data of symptoms, causes and reasons for the critical defects. Furthermore, the system is not supported with the decision-making processes on defect assessment for the reference action. The uncertainty of maintenance retrieving and waste control will emerge in prioritising the

specific maintenance on both data and analysis for building facility. This allows the repetition of defects to happen without realising the actual main causes and will result in the unexpected losses to optimise the maintenance for most sophisticated GB facilities (e.g. vegetative roof and lighting system) in the construction industry.

After the related literature was found, the result was identified to study and explore the particular GB maintenance management processes that should be improved in maintenance management and to consider the necessity of using software programming and database for the new approach in developing the ICT-based maintenance management system at GB projects. This could mean, for example, gathering data from meeting room and hot-desk booking systems, external information such as defect and weather reports to anticipate critical times and environmental requirements.

3. Components in GB maintenance processes

According to Geng *et al.* (2019), GB maintenance can be viewed as part of a triangle in which the contractor must attain the building condition level as planned, meet the schedule repair deadlines and achieve the required quality level. GB maintenance also can be characterised by meeting the requirements of the construction design, the contract plans, adequate building materials, the public safety and health, environmental considerations and protection of property including utilities (Yu *et al.*, 2017). Presently, the GB maintenance system is relying on the monitoring, retrieving and waste control. Quality monitoring or retrieving refers to the system controlling the provision of a product or service for the purpose of satisfying the customer needs. Meanwhile, the GB waste control conforms this quality maintenance program in accordance with all contractual specifications, codes and standards or government regulations for assuring that the planning of a specific project is being performed effectively (El-Diraby *et al.*, 2017). Waste control is also the performance measurement process provided with the priority standard for the materials and construction design, either by inspection or by sample testing approaches (Huo *et al.*, 2018). Most GB construction projects have widely used the ISO 9000 as a Quality Management System in order to obtain the improvements in quality procedures and products (Darko and Chan, 2016). However, this maintenance trajectory is not effective due to the alterations when encountering newly developed threats or obstacles (Curry *et al.*, 2013). The data related to the GB construction site are not clearly identified in capturing and modelling a project's information to control the construction quality processes such as building cost accounting view and design specification. An initial data inspection using the tools and techniques currently in use is captured manually such as using dispersed documents and CMMS databases, resulting in missing information and errors. The paper-based form is still the main medium for the information transfer and sharing within the industry and affects the criticality for the information collection to assign the problems on phases of construction or even to the maintenance phase (Vyas and Jha, 2017). In addition, the low-level staff competency drives the maintenance towards the assessment issue with the presence of uncertainty and disturbance (Hammad *et al.*, 2016). Mostly, the GB maintenance system is a conventional method application, which is not much documented in terms of its impact on the practices of quality inspection and maintenance management planning for the specific GB management systems. This medium of communication makes it difficult for clients and contractors to obtain up-to-date information and virtually impossible to resolve processes such as requests for information within the required time (Zhang *et al.*, 2017). Due to these limitations, the project managers and construction GB maintenance managers are often constrained with the limited information about the construction projects on various dimensions. Therefore, this lack of quality improvement processes indicates the key barriers to the effective GB maintenance management practices in a variety of areas such as scheduling, simulation and modelling in construction projects (Djedjig *et al.*, 2017).

4. Current issues in GB maintenance project

Maintenance management is an important function of sustainable development analytical tool in the GB technologies (GBTs) research (such as wind turbines and solar panels) in order to provide indications of assessment and planning integration collaborative working between engineers and clients as well as effective building services including use of renewable energy, and minimising lifecycle labour inputs, costs or carbon emissions (Love *et al.*, 2012). Yudelson (2012) considered GB functions as a form of technological and process innovation, which include developing unique building products that can reduce the environmental impact of buildings and integrating a variety of special building technologies, techniques, practices and materials to achieve sustainability. The barriers of GB such as lack of GBTs' databases or information management, GB expertise/skilled labour of contractor's services delivery and fewer GB codes/regulations available on establishing a baseline to evaluate existing green building rating tools during operation assessment and monitoring of building maintenance projects will affect the building performance, green innovation and the sustainable value services (Zhang *et al.*, 2017). Seduikyte *et al.* and Berardi (2013) stated that productions for solid wastes and global carbon dioxide (CO_2) emissions may range from 30 to 40 per cent and 35 to 50 per cent, respectively, particularly because they are a major contributor to energy consumption. In addition, WGBT (2016) indicates that almost 18 per cent of firms certified GB maintenance in 2016 consists of reliable project's database and sustainability tools indication. The number is considered very small, indicating that the use of modern ICT is still very limited for GB projects worldwide. Therefore, there is a need for efficient maintenance management practices in order to improve operation assessment and employee productivity in GB maintenance projects.

There are many issues that contribute to poor GB performance in maintenance projects. Darko *et al.* (2017) suggested that resistance to change into modern ICT or tools of knowledge in GB management process, shortage of skilled workers, higher projects costs, longer implementation time services delivery for fulfilling green maintenance requirements and a lack of awareness of GB adversely affect maintenance management practices in GB projects. In addition, the common issues in relation to GB maintenance projects are as follows:

- improper detail working of green technologies and interactions (Aktas and Ozorhon, 2015);
- availability of deficient GB maintenance rating systems and labelling programs (Djokoto *et al.*, 2014);
- lack of availability of demonstration projects (Zhao *et al.*, 2015);
- lack of GB expertise/skilled worker (Elmualim *et al.*, 2012);
- insufficient information about maintenance, repair and renewal planning (Gou *et al.*, 2013);
- insufficient information among clients and contractors about maintenance management practices in GB projects (Gan *et al.*, 2015);
- insufficient coordination among client and contractor organisation (Zhao *et al.*, 2015); and
- reliable green supplier's issues among team players (Shi *et al.*, 2013).

Presently, the sharing of information for an inspection process in the GB maintenance projects between parties (e.g. contractor, consultant and supplier) is limited to the paper-based file application with inaccurate information and poor accessibility of data collection. In general, the sharing of information is concerned with the building design, plans, as-builts and specifications in a GB maintenance database. This approach currently relies on the initial maintenance database without change orders and modifications due to standardisation code;

also, it is kept in the dead storage. Thus, the conflict of interest is potential to be emerged with the lack of performance-based specifications and impact on the sustainability of maintenance operations for GB maintenance project's success (Silva and Ruano, 2018). Another problem due to the timely sharing of precise information is the lack of software integration in the GB industry. There are several specific software programs in the market, but they have not supported the construction projects in facilitating smooth transfer of information to predict the unexpected level of poor performance of buildings, energy crises, unusual weather events and CO_2 change in rehabilitation projects (Mota *et al.*, 2018). Mostly, the GB maintenance has not yet used information technology to replace paper for many types of documents effectively to integrate its design specification, construction and operational processes. In particular, site staff members normally handle various papers and field notes, such as test forms, specifications, checklists and reports. The building quality measurements include the information delivery specification, for example a highly standardised and consistent dimension of GB maintenance components to mitigate conflicts or frequency and severity of climate change and over-exploitation of resources (Balaban and Oliveira, 2017).

Meanwhile, according to Sharma (2018), there is no simpler system to describe information content requirements, specification for the GB maintenance management practices and information exchanges in the construction projects. The integration of information deliveries with project plan presents unclear protocols of energy efficiency and indoor wellbeing technologies, for instance, criteria assessment of control systems, lighting, ventilation, thermal storage and heat recovery, might be untraceable in the temperature results between indoors, outdoors and building envelope for the GB industry standardisation. Thus, there is an urgent need for a simple, user-friendly method of describing, in a commonly understood way, and a need to develop practice levels for consultants, manufacturers and contractors for improving efficiency of information exchanges to assess the environmental impact during the maintenance stage in protected GBs, such as higher initial cost, imperfect information and uncertainty (technical, regulatory, policy, etc.) (Ulubeyli and Kazanci, 2018; Chatterjee *et al.*, 2018).

5. Reasons for maintenance management issue in GB maintenance project

Many factors affect GB maintenance performance in such projects. Azari and Kim (2016) and Inyim *et al.* (2014) suggested that the main reasons for poor maintenance performance on GB were fault information exchange, less collaborative partnership, technical difficulty during the maintenance assessment process, lack of knowledge and awareness of green technologies and conflict of interest between various stakeholders that turn GB into higher rates of defects and excessive costs for green design and energy-saving material. Green design and energy-saving material are commonly defined as the interaction between design solutions and eco materials so the contractors would be able to reduce the maintenance/replacement costs over the life of the building and the environmental impacts associated with the extraction, transport, reuse, recycling and disposal of these GB source materials across a range of green retrofit and renovation projects. Aktas and Ozorhon (2015) also suggested that inexperience of the contractor who is responsible for the GB technical structure including strategy for decision-making process in defect diagnosis was a major cause of limitations in the GB facilities maintenance process. Thus, it would seem that poor service delivery by contractor is a major cause of poor maintenance performance in GB maintenance projects. There is a possibility of conflict of interest with the knowledge misconceptions of LEED/GBI requirements for the service-based maintenance specifications and impact of the client's satisfaction (Hwang and Tan, 2012). In addition, the contractors face difficulty to collaborate with the specific consultant through generic communication due to the nature of the Malaysian GB maintenance process that is conducted in a sequential manner, which is based on segregation of professionals during the design, construction and

maintenance phase, subsequently contributing to the ineffectiveness of maintenance approach such as knowledge and competency management; however, the GB maintenance services delivery could not have refined it accordingly (Chiang *et al.*, 2015).

In order to make maintenance on-site effective for GB projects, there should be complementarity between the contractor and consultant for implementing an integrated approach in the maintenance optimisation (e.g. sustainability building) to facilitate new communication platforms that are operational best for GB maintenance projects in the future.

6. Need for improvement

GB of maintenance management in GB projects is still not benefiting from potential improvement, as it still uses limited sources of data and options for the investigation and integration of data streams. It is useful in improving maintenance services such as to manage huge amounts of data, complicated data and defect assessments in inappropriate database. Thus, Green Building Maintenance Management System (GBMMS) is proposed in order to improve the conventional method that tends to be cumbersome in GB projects. The GBMMS is developed by adapting the new approaches from sensor and bio-inspired computing to identify components' requirements and behaviours towards sophisticated management of maintenance management process in GB projects. This technique solves complex issue in the computer technology, hardware and software using the sensor and biological systems. These sensor and biological systems exhibit complex, intelligent and organised behaviour to support the monitoring of hierarchical and distributed GB strategy, which realises the concurrent operation of reusable GB components. Essentially, the GBMMS has the potential transform maintenance processes to one of the most sophisticated technologies in GB projects.

7. Constructability concept of GB maintenance

A constructability concept is about knowledge and experience analysis resulted from identification of potential problems, causes and reasons to meet the strategy objectives (Khan, 2015). This approach is able to identify the efficiency solution and provide decision-making processes that facilitate management in the organisation. In this paper, the conventional method in maintenance processes become the components of constructability improvement to define the problems, capture and transfer lesson learned to future GB projects at Malaysian construction industry. Essentially, the contractor and consultant take the responsibility to implement the maintenance for the building facilities and infrastructures in GB projects (Azari and Kim, 2016; Thatcher and Milner, 2016).

There is an approach to improve the GB maintenance project and practices through various automation efforts such as Building Information Modelling (BIM) and mobile devices. However, these automation efforts have been limited for accessing the real-time information for the as-built condition and active maintenance control between the collection of information and inspection in terms of productivity, quality compliance and efficiency. These existing approaches of paper-based and other automated systems also still rely on the manual judgment systems. In this research, the new information system theoretical framework is proposed to improve the maintenance management practices in GB building construction. The new information system theoretical framework is expected to support the GB maintenance approach in managing construction projects. In conclusion, the information system theoretical framework could assist communications and quick decision-making in inspection to efficiently operate the GB building projects.

8. Proposed theoretical framework

Son *et al.* (2015) stated that constructability concept is an effective approach to enhance the performance of structure and facility by integrating construction expertise (e.g. ICT) into the

planning and strategy of a project. This definition of constructability concept will be the basis for developing a theoretical framework for this research, but stress is given on the maintenance management for GB facility. The theoretical framework consists of a few stages in order to establish the requirement for integrating maintenance management processes and elements of good practice in pre-development of GBMMS. This is also concerned with suitable software programming application with respect to system effectiveness. There are two theories in the development of GBMMS, namely wireless sensor networks (WSNs) and bio-inspired systems, as shown in Figure 1. The purpose of these theories is to construct the components of BIM and CMMS to design the GBMMS. A total of four main ICT tools based on system process were described and illustrated in Figure 2, which are determined as key aspects for tool improvement of GBs that constitute vulnerabilities and resilience characteristic.

9. System application

As they are related to this research, in-depth explanations of WSNs, bio-inspired systems, BIM and CMMS are provided as follows.

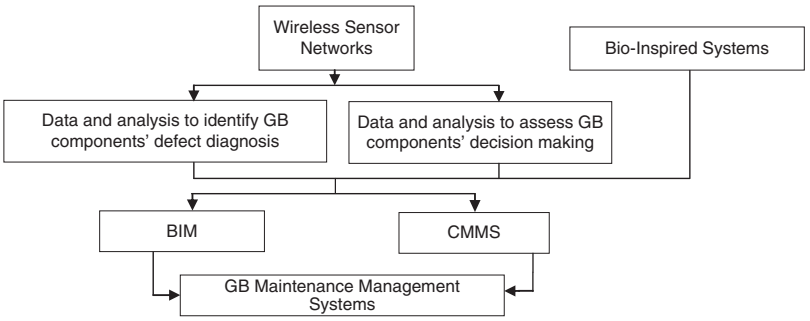

Figure 1.
Theoretical framework

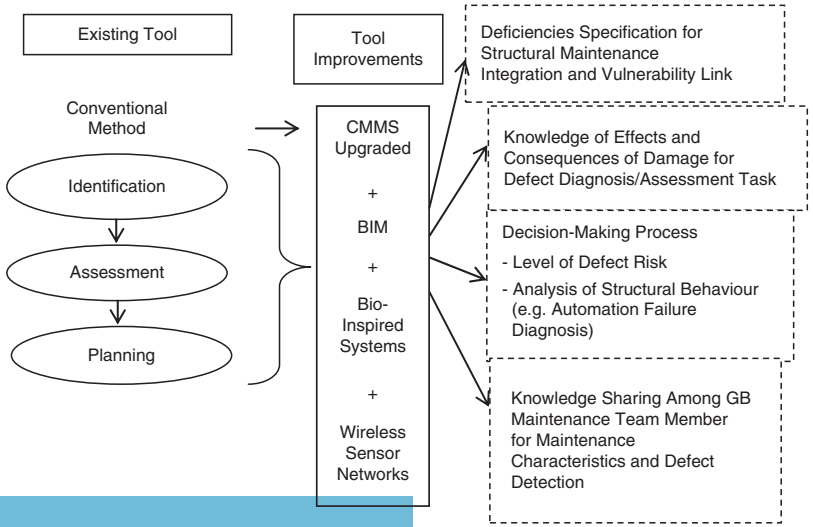

Figure 2.
Key aspects for tool improvements in GB maintenance technology

Wireless sensor networks

WSN is the most emerging and multi constraint (energy, memory and computational as well as bandwidth) technology. This is an upgraded application compared to the traditional wireless networks such as Ad hoc network of the cellular network, which has a long period operation in the energy constraint environment, densely and randomly deployed nodes, high node failure and other constraint resources (Cui *et al.*, 2017). Mostly, WSN is applied for the geographical monitoring, monitoring of structures, vital sign monitoring, ocean water and bed monitoring, monitoring of fresh water quality, volcano monitoring and tunnel monitoring, and rescue (Yadav and Daniel, 2016). WSN provides data from multiple platforms to co-ordinate and deliver maintenance services throughout a GB's lifecycle. This application covers the wide spectrum of building and infrastructure components such as specifying work location, labour, material and equipment needed as well as desired completion date (Han *et al.*, 2016). With global technology for local markets, WSN will not only be digitally integrated into the global net, but it will also be a physical catalyst for local business as well as social and cultural ecosystems. WSN also supports the GB maintenance management budget and long-term financial commitment to attain returns benefits of financial management (Kim *et al.*, 2015).

Bio-inspired computing

Presently, biologically inspired, converged and hybrid information technologies have become of significant interest due to their capabilities in handling many real-world complex problems, which involve imprecision, uncertainty and vagueness and high dimensionality (Aziz, 2016). In the biological systems, there are many cases where complexity is handled by individuals with limited capabilities. However, by using simple rules for the behaviour and an interaction among individuals, a global optimum can be achieved on a large, system-level scale (Tsavdaridis *et al.*, 2015). In addition, many researchers are now inclining towards biologically inspired solutions to gain maximum productivity from brainstorming solutions (e.g. network sensor system). The inspiration from the brainstorming solutions is created through the insight concentration for the nature and creation to produce the miraculous architecture. The intense exploitation of this miraculous architecture is named as biologically inspired computing (BC). BC is a technique to formulate the views, ideas, technologies and algorithms in resolving the issues with an innovation technology (e.g. computer, hardware and software) (Jabbar *et al.*, 2013). BC represents a class of algorithms focusing on the efficient computing in applications such as optimisation processes and pattern recognition (Lopez *et al.*, 2015).

Computerised maintenance management systems (CMMS)

Globally, good assessment of the maintenance status of a building and its high component durability over time are known to impact the safety of the service life of GBs in general. Leung (2018) stated that safety of building service process depends on the methods and techniques used to perform specific functions of identifying, analysing and determining the scope planning of maintenance activities, which include constructive system, fire, environmental conditions, ventilation or the geological location of the GB. Proper management and a high level of technical application of CMMS during a GB maintenance activity will influence the financial and quality performance factors, such as appropriate design of changes and updates, reasonable costs and selection of materials (e.g. consolidants and protective coatings) as well as good environmental situation, in general, and GBs, in particular (Gupta *et al.*, 2018; Mantha *et al.*, 2018). CMMS are among the approaching technologies utilised for reducing the downtime of equipments and facilitating the accessibility information to the staff for GB maintenance management (Hamzah *et al.*, 2016). CMMS is the technology management and includes all computer

systems and networks, building automation systems such as control systems and programmable logic controllers, design drawing databases, an all diagnostic and monitoring system (Muchiri *et al.*, 2017).

Building information modelling (BIM)

GB maintenance management in Malaysia has experienced inevitable loss from decay and natural hazards such as earthquakes and floods including theft, neglect and vandalism, which are human factors in the accidental destruction of GB. Integrating analysis from BIM applications for strategic planning and good measurement usage ensures long-term maintenance in GB maintenance activities. BIM is defined as the use of ICT technologies to improve the building construction processes to be more operationally maintained throughout the GB lifecycle (Ghaffarianhoseini *et al.*, 2017). The use of BIM application in construction sites has been observed for a prominent benefit of better production quality towards the documentation output. The data transfer in the documentation are flexible and exploit automation for the maintenance diagnosis information, which enable to trace the concerned information regarding GB components in the construction projects (Zuo *et al.*, 2017). According to Ilhan and Yaman (2016), the maintenance management practices in the GB construction projects become efficient by developing a BIM model in a remote construction project. This BIM model can provide the effective GB design and technical review to improve the consistency and accuracy of data investigation for the GB management in the future such as changes to specifications, specified materials and effective maintenance strategy for structural optimisation (Eleftheriadis *et al.*, 2017).

The characteristic features of WSNs, bio-inspired systems, CMMS and BIM are summarised in Table I.

10. Implementation of ICT application in GB maintenance management

ICT application has been practiced recently to ease the management in GB building maintenance as well as to ensure the completion of project on time, without any difficulties. Many construction companies, as well ascontractors, suppliers and clients, are less exposed to intelligent approaches such as WSN, BC and BIM for improvement in the quality implementation because of the particular factors such as GB design planning, analysis and specification management (Radu, 2016).

The additional aspects for GBMMS implementation in this research are as follows:

(1) to measure the quality performance of GB component's protection (e.g. light, temperature, relative humidity and indoor air pollution);

Characteristic features	Wireless sensor networks	Bio-inspired systems	CMMS	BIM
Manipulation and use of large databases	/	/		/
Control and knowledge integration	/			/
Algorithmic process	/			
Heuristic process		/		
Representation of data			/	
Gives results without analysis	/		/	
Gives results with diagnosis explanation		/		/
Orientated towards numerical processing		/		
Calculates result		/		
Makes decision			/	
Requires complete information				/

Table I.
Characteristic features of GB maintenance technology

(2) to plan the quality operation and appropriate recommendations for optimising GB risk effectively;

(3) to timely execute the work repair order concerning the variable environmental conditions, air and indoor pollution, impact of HVAC on the deteriorated structural components;

(4) to reduce the environmental effects and operative costs of GB construction material;

(5) to evaluate the parameters of the factors threatening GB and safety threats including preventive maintenance appropriately; and

(6) to estimate the buildings' degradation level towards GB refurbishment solution of an asset.

Based on Figure 1, it is observed that the GBMMS theoretical framework is complete with the data documentation such as history of facility maintenance services to support the inspection operation, tabulated diagnosis information and quality decision-making management processes. The specific information in the database modelling is achieved with a short duration to optimise resources and allowing massive supervision of structures contained in building design, including to establish the extent of deterioration zone for proper classification of components to decide any actions to be implemented. The theoretical framework monitors the quality of GB building component continuously in order to improve the collaboration efficiency for the sustainable protection, organisational disintegration and high fragmentation of integrated process for on-going maintenance (e.g. environmental assessment and safety standards) to be solved. In the implementation of GBMMS theoretical framework, this research has also developed the network to manage the quality operation for the federal GB building facility and infrastructure. The theoretical framework will assist the staff for the GB design planning, analysis and specification management in the future. Moreover, with this theoretical framework, the database has been able to issue the subject related to future behaviour such as defect scenarios and causes of degradation including performance of an existing GB (e.g. possible daylighting design, structural reliability and safety levels), with a view to mitigate adverse impacts and enhance quality outcome. The new GB construction project information, which is under progress, is updated into the database recorded in case of occurrence of construction design faults or low-quality project. In addition, the framework application has been able to identify the GB defects on the facility property based on the specification through feedback in the web-based network development presentation.

11. Research implication

The theoretical framework is demonstrated to end users. Focus group discussion (FGD) method was conducted for evaluation sessions. FGD was conducted in a place provided by the Public Works Department (JKR) Malaysia organisation. To assess the model framework, ten professionals working in various JKR departments with knowledge of BIM technology participated in the FGD. The place chosen for discussion had been carefully conducted so that professionals could carry out the tasks provided about the main requirements or specifications contained in the theoretical framework and in the verification report. The FGD was started with a briefing on the introduction of research topics and a brief background on the core of the theoretical framework. The goals and objectives of the FGD were also explained to the professionals.

Table II shows a summary of key requirements or specifications contained in the model framework in line with JKR Malaysia organisation, comprising Environmental and Energy Efficiency (CASKT), which were included in the FGD. The use of existing system specifications in JKR is based on the conventional maintenance management systems, which are Green Product Scoring System and paper-based report.

Evaluation of key requirements or specifications in process structure has shown that the framework improves the quality of decision-making in the process, which is not available in the conventional systems. The following sections discuss lesson reports and their enlightenments on the theoretical framework by professionals from the FGD.

12. Lessons and enlightenments

- Both the scientific and engineering research studies used ICT integration methodology for its intelligent approach.
- A transmits information that includes some environmental characterisation, structural system, alterations in terms of unfavourable environmental conditions (i.e. biotic decay), effect of natural hazardous damaging events (i.e. earthquake, flood, hurricane) and aggressive agents (fire and other chemical agents) between the flows are fast since there are fewer parameters to adjust because no overlapping and mutation calculation.
- BC methodology has an effective result capability to provide specific adaptive management strategies that will increase the resilience of GB landscapes and the adaptive capacities of GB sites.
- BIM methodology adopts the number of the dimensions to develop a mitigation strategy in order to support a more systematic framework for assessing and justifying potential impacts of GB maintenance using the results from the decision-makers.

13. Conclusions

The constructability concept is extended towards the system development in maintenance processes of GB projects. It elaborates the available maintenance problems and their potential causes and reasons. Productivity management relies on the methods used for GB maintenance management. The constructability result identified that the conventional method leads to some potential effect of negligent maintenance due to limited sources of measurement data and defect parameter values relating to technology option with analytical approaches. There was also a need for proper training for the effective implementation of the GB maintenance practice in such projects. Based on analysis of amendments and probable solution, initial extended components are developed, which are BIM and CMMS that can be used in producing the GBMMS. The GBMMS application highlights the original contribution in improving GB component diagnosis knowledge integration and decision-making that consisted of three substantive areas as follows:

- Integration of BC and WSN technology with building assessment/diagnosis.

  In this research, the theoretical framework is able to integrate the related BC and WSN with the building diagnosis data in order to provide better design defect

Specifications of theoretical framework that meet the needs of the JKR Malaysia organisation		Existing framework specifications in JKR
Modelling using BIM technology	/	X
Maintenance condition index	/	/
Green condition index	/	/
Generates response for current conditon of structure	/	X
Generates response for risk of GB defect	/	X
Facilitate automatic decision-making with flexibility (integration of BC and CMMS)	/	X

Table II. Specifications of theoretical framework

analysis for identifying and assessing risks of failure for GB components. The development of the new theoretical framework with the integration of the building diagnosis data provides the report of knowledge of the nature of defects components and their cause for the GB designer's benefit.

- The BIM database through integration with CMMS.

  In the information database, the integration of BIM database with the CMMS could support the decision-making efficiency in order to improve the durability and reduce the need for GB maintenance. In addition, the time consumed for design defect analysis can be decreased because of the reliable information on principles and solutions based on the designs and specifications.

Further research on socio-technical systems is required to enable the theoretical framework to be better integrated into GB maintenance management practices in the future. This is required to study the social aspects of people and society, and technical aspects of technology to find out the specific links with smart buildings operation of the system. Besides, this can improve the theoretical framework to be more effective in building performance analysis in the GB maintenance management.

References

Aktas, B. and Ozorhon, B. (2015), "Green building certification process of existing buildings in developing countries: cases from Turkey", *Journal of Management in Engineering*, Vol. 31 No. 6, pp. 1-9.

Azari, R. and Kim, Y. (2016), "Integration evaluation framework for integrated design teams of green buildings: development and validation", *Journal of Management in Engineering*, Vol. 32 No. 3, pp. 1-14.

Aziz, M.S. (2016), "Biomimicry as an approach for bio-inspired structure with the aid of computation", *Alexandria Engineering Journal*, Vol. 55 No. 1, pp. 707-714.

Balaban, O. and Oliveira, J.A.P.D. (2017), "Sustainable buildings for healthier cities: assessing the co-benefits of green buildings in Japan", *Journal of Cleaner Production*, Vol. 163 No. 2017, pp. 568-578.

Berardi, U. (2013), "Clarifying the new interpretations of the concept of sustainable building", *Sustainable Cities and Society*, Vol. 8 No. 2013, pp. 72-78.

Chatterjee, S., DuttaGupta, S. and Upadhyay, P. (2018), "Sustainability of microenterprises: an empirical analysis", *Benchmarking: An International Journal*, Vol. 25 No. 3, pp. 919-931.

Chiang, Y.H., Li, J., Zhou, L., Wong, F.K.W. and Lam, P.T.I. (2015), "The nexus among employment opportunities, life-cycle costs, and carbon emissions: a case study of sustainable building maintenance in Hong Kong", *Journal of Cleaner Production*, Vol. 109 No. 2015, pp. 326-335.

Cui, Z., Sun, B., Wang, G., Xue, Y. and Chen, J. (2017), "A novel oriented cuckoo search algorithm to improve DV-Hop performance for cyber–physical systems", *Journal of Parallel and Distributed Computing*, Vol. 103 No. 1, pp. 42-52.

Curry, E., O'Donnel, J., Corry, E., Hassan, S., Keane, M. and O'Riain, S. (2013), "Linking building data in the cloud: integrating cross-domain building data using linked data", *Advanced Engineering Informatics*, Vol. 27 No. 2, pp. 206-219.

Darko, A. and Chan, A.P. (2016), "Critical analysis of green building research trend in construction journals", *Habitat International*, Vol. 57 No. 2016, pp. 53-63.

Darko, A., Zhang, C. and Chan, A.P.C. (2017), "Drivers for green building: a review of empirical studies", *Habitat International*, Vol. 60 No. 2017, pp. 34-49.

Djedjig, R., El Ganaoui, M., Belarbi, R. and Bennacer, R. (2017), "Thermal effects of an innovative green wall on building energy performance", *Mechanics & Industry*, Vol. 18 No. 1, pp. 104-112.

Djokoto, S.D., Dadzie, J. and Ohemeng-Ababio, E. (2014), "Barriers to sustainable construction in the Ghanaian construction industry: consultants' perspectives", *Journal of Sustainable Development*, Vol. 7 No. 1, pp. 134-143.

El-Diraby, T., Krijnen, T. and Papagelis, M. (2017), "BIM-based collaborative design and socio-technical analytics of green buildings", *Automation in Construction*, Vol. 82 No. 2017, pp. 59-74.

Eleftheriadis, S., Mumovic, D. and Greening, P. (2017), "Life cycle energy efficiency in building structures: a review of current developments and future outlooks based on BIM capabilities", *Renewable and Sustainable Energy Reviews*, Vol. 67 No. 1, pp. 811-825.

Elmualim, A., Valle, R. and Kwawu, W. (2012), "Discerning policy and drivers for sustainable facilities management practice", *International Journal of Sustainable Built Environment*, Vol. 1 No. 1, pp. 16-25.

Ferwati, M.S., Saeed, M.A., Shafaghat, A. and Keyvanfar, A. (2019), "Qatar sustainability assessment system (QSAS)-neighborhood development (ND) assessment model: coupling green urban planning and green building design", *Journal of Building Engineering*, Vol. 22 No. 2019, pp. 171-180.

Gan, X., Zuo, J., Ye, K., Skitmore, M. and Xiong, B. (2015), "Why sustainable construction? Why not? An owner's perspective", *Habitat International*, Vol. 47 No. 2015, pp. 61-68.

Geng, Y., Lin, B., Yu, J., Zhou, H., Ji, W., Chen, H., Zhang, Z. and Zhu, Y. (2019), "Indoor environmental quality of green office buildings in China: large-scale and long-term measurement", *Building and Environment*, Vol. 150 No. 2019, pp. 266-280.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O. and Raahemifar, K. (2017), "Building information modelling (BIM) uptake: clear benefits, understanding its implementation, risks and challenges", *Renewable and Sustainable Energy Reviews*, Vol. 75 No. 1, pp. 1046-1053.

Gou, Z., Lau, S.S.Y. and Prasad, D. (2013), "Market readiness and policy implications for green buildings: case study from Hong Kong", *Journal of Green Building*, Vol. 8 No. 2, pp. 162-173.

Gupta, S., Kumar, S., Singh, S.K., Foropon, C. and Chandra, C. (2018), "Role of cloud ERP on the performance of an organization: contingent resource based view perspective", *International Journal of Logistics Management*, Vol. 29 No. 2, pp. 659-675.

Hammad, A.W., Akbarnezhad, A. and Rey, D. (2016), "A multi-objective mixed integer nonlinear programming model for construction site layout planning to minimise noise pollution and transport costs", *Automation in Construction*, Vol. 61 No. 2016, pp. 73-85.

Hamzah, N., Ismail, Z.A., Kamaruzzaman, S.N., Mutalib, A.A. and Ani, A.I.C. (2016), "A CMMS expert using BIM for IBS building maintenance", *4th International Building Control Conference in Bangsar, Kuala Lumpur, EDP Sciences*, pp. 1-10.

Han, J., Lee, J., Lee, E. and Kim, D.S. (2016), "Development of a low-cost indoor environment monitoring system based on a hybrid wireless sensor network", *International Conference on Consumer Electronics in Berlin, IEEE, NJ*, pp. 461-462.

Huo, X., Ann, T.W.Y. and Zezhou, W. (2018), "An empirical study of the variables affecting site planning and design in green buildings", *Journal of Cleaner Production*, Vol. 175 No. 2018, pp. 314-323.

Hwang, B.G. and Tan, J.S. (2012), "Green building project management: obstacles and solutions for sustainable development", *Sustainable Development*, Vol. 20 No. 5, pp. 335-349.

Ilhan, B. and Yaman, H. (2016), "Green building assessment tool (GBAT) for integrated BIM-based design decisions", *Automation in Construction*, Vol. 70 No. 1, pp. 26-37.

Inyim, P., Rivera, J. and Zhu, Y. (2014), "Integration of building information modeling and economic and environmental impact analysis to support sustainable building design", *Journal of Management in Engineering*, Vol. 31 No. 1, pp. 1-11.

Jabbar, S., Iram, R., Minhas, A.A., Shafi, I., Khalid, S. and Ahmad, M. (2013), "Intelligent optimization of wireless sensor networks through bio-inspired computing: survey and future directions", *International Journal of Distributed Sensor Networks*, Vol. 9 No. 2, pp. 1-13.

Khan, S. (2015), "An overview of constructability: a management tool for architects", *Architecture Research*, Vol. 5 No. 5, pp. 125-139.

Kim, A., Han, J., Yu, T. and Kim, D.S. (2015), "Hybrid wireless sensor network for building energy management systems based on the 2.4 GHz and 400 MHz bands", *Information Systems*, Vol. 48 No. 1, pp. 320-326.

Leung, B.C. (2018), "Greening existing buildings [GEB] strategies", *Energy Reports*, Vol. 4 No. 2018, pp. 159-206.

Lopez, M., Rubio, R., Martín, S., Croxford, B. and Jackson, R. (2015), "Active materials for adaptive architectural envelopes based on plant adaptation principles", *Journal of Facade Design and Engineering*, Vol. 3 No. 1, pp. 27-38.

Love, P.E., Niedzweicki, M., Bullen, P.A. and Edwards, D.J. (2012), "Achieving the green building council of Australia's world leadership rating in an office building in Perth", *Journal of Construction Engineering Management*, Vol. 138 No. 5, pp. 652-660.

Mantha, B.R.K., Menassa, C.C. and Kamat, V.R. (2018), "Robotic data collection and simulation for evaluation of building retrofit performance", *Automation in Construction*, Vol. 92 No. 2018, pp. 88-102.

Mohammad, I.S., Zainol, N.N., Abdullah, S., Woon, N.B. and Ramli, N.A. (2014), "Critical factors that lead to green building operations and maintenance problems in Malaysia", *Theoretical and Empirical Researches in Urban Management*, Vol. 9 No. 2, pp. 68-86.

Mota, L., Mota, A., Pezzuto, C., Carvalho, M., Lavorato, M., Coiado, L. and Oliveira, E. (2018), "Development of a surface temperature sensor to enhance energy efficiency actions in buildings", *Sensors*, Vol. 18 No. 9, pp. 1-16.

Muchiri, A.K., Ikua, B.W., Muchiri, P.N. and Irungu, P.K. (2017), "Development of a theoretical framework for evaluating maintenance practices", *International Journal of System Assurance Engineering and Management*, Vol. 8 No. 1, pp. 198-207.

Ravindu, S., Rameezdeen, R., Zuo, J., Zhou, Z. and Chandratilake, R. (2015), "Indoor environment quality of green buildings: case study of an LEED platinum certified factory in a warm humid tropical climate", *Building and Environment*, Vol. 84 No. 2015, pp. 105-113.

Radu, L.D. (2016), "Determinants of green ICT adoption in organizations: a theoretical perspective", *Sustainability*, Vol. 8 No. 8, pp. 1-16.

Sharma, M. (2018), "Development of a 'Green building sustainability model' for Green buildings in India", *Journal of Cleaner Production*, Vol. 190 No. 2018, pp. 538-551.

Shi, Q., Zuo, J., Huang, R., Huang, J. and Pullen, S. (2013), "Identifying the critical factors for green construction – an empirical study in China", *Habitat International*, Vol. 40 No. 2013, pp. 1-8.

Silva, S. and Ruano, A. (2018), "The IMBPC HVAC system: wireless sensors and IoT platform", *IFAC-PapersOnLine*, Vol. 51 No. 10, pp. 1-8.

Son, H., Lee, S. and Kim, C. (2015), "An empirical investigation of key pre-project planning practices affecting the cost performance of green building projects", *Procedia Engineering*, Vol. 118 No. 1, pp. 37-41.

Thatcher, A. and Milner, K. (2016), "Is a green building really better for building occupants? A longitudinal evaluation", *Building and Environment*, Vol. 108 No. 1, pp. 194-206.

Tsavdaridis, K.D., Kingman, J.J. and Toropov, V.V. (2015), "Application of structural topology optimisation to perforated steel beams", *Computers & Structures*, Vol. 158 No. 1, pp. 108-123.

Ulubeyli, S. and Kazanci, O. (2018), "Holistic sustainability assessment of green building industry in Turkey", *Journal of Cleaner Production*, Vol. 202 No. 2018, pp. 197-212.

Vyas, G.S. and Jha, K.N. (2017), "Benchmarking green building attributes to achieve cost effectiveness using a data envelopment analysis", *Sustainable Cities and Society*, Vol. 28 No. 2017, pp. 127-134.

WGBT (2016), "World green building trends, smart market report", available at: http://fidic.org/sites/default/files/World%20Green%20Building%20Trends%202016%20SmartMarket%20Report%20FINAL.pdf (accessed 3 July 2017).

Yadav, M. and Daniel, A.K. (2016), "Performance analysis of approaches for coverage issues in WSN", *3rd International Conference on Computing for Sustainable Global Development (INDIACom) in New Delhi, IEEE, NJ*, pp. 782-787.

Yu, L., Wang, H., Wang, X. and Feng, G. (2017), "Study on the measurement of indoor environment quality and enclosure structure thermal defects of green residential buildings in severe cold areas", *Procedia Engineering*, Vol. 205 No. 2017, pp. 3373-3380.

Yudelson, J. (2012), *Green Building Trends: Europe*, Island Press, Washington, DC.

Zhang, Y., Wang, J., Hu, F. and Wang, Y. (2017), "Comparison of evaluation standards for green building in China, Britain, United States", *Renewable and Sustainable Energy Reviews*, Vol. 68 No. 2017, pp. 262-271.

Zhao, D.X., He, B.J., Johnson, C. and Mou, B. (2015), "Social problems of green buildings: from the humanistic needs to social acceptance", *Renewable and Sustainable Energy Reviews*, Vol. 51 No. 2015, pp. 1594-1609.

Zuo, J., Pullen, S., Rameezdeen, R., Bennetts, H., Wang, Y., Mao, G., Zhou, Z., Du, H. and Duan, H. (2017), "Green building evaluation from a life-cycle perspective in Australia: a critical review", *Renewable and Sustainable Energy Reviews*, Vol. 70 No. 1, pp. 358-368.

Further reading

Fan, Y. and Xia, X. (2018), "Energy-efficiency building retrofit planning for green building compliance", *Building and Environment*, Vol. 136 No. 2018, pp. 312-321.

Png, E., Srinivasan, S., Bekiroglu, K., Chaoyang, J., Su, R. and Poolla, K. (2019), "An internet of things upgrade for smart and scalable heating, ventilation and air-conditioning control in commercial buildings", *Applied Energy*, Vol. 239 No. 2019, pp. 408-424.

Schmidt, M. and Ahlund, C. (2018), "Smart buildings as cyber-physical systems: data-driven predictive control strategies for energy efficiency", *Renewable and Sustainable Energy Reviews*, Vol. 90 No. 2018, pp. 742-756.

Si, B., Tian, Z., Jin, X., Zhou, X., Tang, P. and Shi, X. (2016), "Performance indices and evaluation of algorithms in building energy efficient design optimization", *Energy*, Vol. 114 No. 2016, pp. 100-112.

Tam, W.Y.V., Le, K.N., Tran, C.N.N. and Wang, J.Y. (2018), "A review on contemporary computational programs for building's lifecycle energy consumption and greenhouse-gas emissions assessment: an empirical study in Australia", *Journal of Cleaner Production*, Vol. 172 No. 2018, pp. 4220-4230.

Wei, Y., Zhang, X., Shi, Y., Xia, L., Pan, S., Wu, J., Han, M. and Zhao, X. (2018), "A review of data-driven approaches for prediction and classification of building energy consumption", *Renewable and Sustainable Energy Reviews*, Vol. 82 No. 2018, pp. 1027-1047.

Corresponding author
Zul-Atfi Ismail can be contacted at: zulatfippkas@gmail.com