INTEGRATING CMMS, EXPERT SYSTEMS AND BIM FOR IBS BUILDING MAINTENANCE

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Current methods of maintenance management have affected the efficiency of the relevant tasks when applied to the industrialised building system (IBS) for high-rises in Malaysia. Many issues, such as poor service delivery, limited budgets, incompetent staff and defect repetition, have emerged from the use of conventional methods of application (paper-based forms). A total of 73.5% of IBS building maintenance tasks in Malaysia feature the conventional method. Data have revealed that the practice of maintenance management for IBS high-rise buildings needs to be digitalised. Therefore, this paper reviews current practices in maintenance management and develops a Building Information Modelling (BIM) prototype system that addresses problems with to the conventional method to improve the processes of maintenance management. This qualitative research was carried out by conducting a literature review and semi-structured interviews. Eight major maintenance organisations were selected based on the conventional method of practice in managing maintenance for IBS high-rise buildings. The framework was represented in a computer-based prototype system in Autodesk Revit to allow multidisciplinary information to be superimposed onto a digital building model, Microsoft Visual Basic.Net was used as graphical-user interface while Microsoft Access was used for database design to deploy information on maintenance management processes. The computerised system was developed using data flow diagrams and coding. The prototype system was then tested, and the results show that it makes defect diagnosis and decision-making process easier, faster, and cost effective while facilitating the assessment of maintenance, defect diagnosis, and control in relation to components of IBS building structures. In conclusion, the prototype system can improve the effectiveness of maintenance management practices for components of the IBS building structure by reducing the risk of defects in design, such as the design calculation error, to provide high-quality components for the structure to ensure a safe and healthy environment.

Keywords: BIM, IBS Building, maintenance, decision making, diagnosis

INTRODUCTION

Building maintenance is poorly managed in construction projects that employ the industrialised building system (IBS). According to Kamar *et al.,* (2012) and Mohamad *et al.,* (2016), aesthetic and structural defects occur more frequently in components of buildings constructed using IBS than those of conventional buildings. Such problems as a lack of integration among maintenance systems, lack of

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coordination between design and construction, insufficient consideration of defect diagnosis in the decision making process, and the absence of a link between operations of defect diagnosis in maintenance that affect various elements of the building and knowledge of defects in components of IBS, have led to significant problems in the maintenance management of IBS buildings. The absence of standard tools of diagnosis and guidelines for prefabricated components contributes to additional cost to redesign the project when measuring the maintenance delivery in IBS construction. This leads to an increase in maintenance and operation costs, including the time taken for construction, and production and labour costs (Yunus and Yang, 2012; Chang and Tsai, 2013). A limited systematic process of decision-making owing to the lack of integration among team members when dealing with risk management in IBS construction projects is also problematic for maintenance management. There is no best method for problem solving and decision making under these circumstances (such as difficulties in maintenance planning, and insufficient knowledge of building materials and requirements of the maintenance of components) (Zakaria *et al.,* 2012; Chiu and Lin, 2014).

Most prevalent process of maintenance management use conventional methods, with little emphasis on decision making and tool of defect diagnosis. In conventional methods, all design and construction processes are conducted in a sequential manner to provide maintenance teams assessing building degradation the choice of optimal maintenance strategies for components or materials in IBS buildings with the minimal lifecycle analysis of projects (e.g. requirements, and operational and maintenance-related information) (Ismail, 2014; Nawi *et al.,* 2014a). The use of ICT technology in the construction industry is now commonplace for facilitating various maintenance-related activities (failure analysis, documentation of maintenance, fault location, repair, and reconstruction). An example of the use of ICT is the bottleneck of massive data between maintenance components and building management, which can now be eliminated by converting raw data on the quality of systems and their process capability into knowledge for dynamic decision making (Ruiz *et al.,* 2013; Kamsu-Foguem and Noyes, 2013). A few researchers have considered IBS to provide more efficient decision support tools for diagnosis, such as the PPMOF (Prefabrication, Preassembly, Modularisation, and Offsite Fabrication), IMMPREST (Interactive Method for Measuring PRE-assembly and Standardisation), PSSM (Prefabrication Strategy Selection Method), and CMSM (Construction Method Selection Model). Nevertheless, these tools do not adequately consider aspects of sustainability (Yunus and Yang, 2012). Sustainability involves such issues as the design and management of buildings, the performance of materials, operation and maintenance, long-term monitoring, and the dissemination of knowledge in related technical contexts. Moreover, most available systems and assessments, including diagnosis guidelines and tools, are used only once the design of the IBS building project is near completion (Nawi *et al.,* 2014b). Due to the uncertainty and complexity of IBS building maintenance and the diversity of project environments, maintenance management needs to be efficient at each stage of the lifecycle of the building.

Applications of CMMS to maintain a large number of buildings with high-quality methods can provide various reports pertaining to repair and maintenance issues that ensure better management of maintenance activities and achieve better quality of the transfer and evaluation of information among internal staff (Bucon and Tomczak, 2018). The CAFM system to improve the usability of buildings can help decision makers automate the organization of a large amount of intensive data for maintenance management functions, and generally results in cost saving on a regular basis (Roka-Madarasz, Malyusz and Tuczai, 2016). At present, Building Information Modelling (BIM) is most often used as a new system in maintenance management processes for high-rise and complex IBS buildings that enable effective maintenance and maintenance-related data. BIM has the potential to help improve the quality of maintenance management by visualising a large amount of data on the building's lifecycle in addition to other software functions (e.g. CMMS and CAFM) (Motamedi *et al.,* 2014; Chien *et al.,* 2017). There are advantages for clients and contractors in using BIM as a digital building model in the maintenance phase, for which it contains detailed building specifications in a system that facilitates computer-based maintenance management controls (e.g. geometric information, functions, features, and parameters), thus allowing for the identification of errors immediately, and build collaboration among various professionals in design to generate improved coordination, and reducing the time needed and defects in buildings (Ghaffarian-Hoseini *et al.,* 2017). Many studies have suggested integrated BIM solutions for various projects throughout the lifecycle of buildings, including its maintenance management. According to Carbonari, Stravoravdis, and Gausden (2016), the conceptual design in the BIM system is ideal for high-rise IBS buildings to support consistent visualization and design, cost estimation, evaluation, monitoring, retrofit planning, lean maintenance, and enhancement of collaboration between maintenance teams. Kensek (2015) investigated the possibility of detecting potential defects using BIM technology in an effort to carry out effective operations and maintenance work, particularly in complex projects. Taghavi *et al.,* (2018) also examined the use of BIM and sensor technology in an integrated manner to identify the state of the building in the construction project and gather information related to defect diagnosis and prevention for IBS building maintenance.

This paper proposes a framework for the application of the BIM-based Computerised Maintenance Management System (CMMS) expert in managing maintenance for high-rise IBS buildings. Using the proposed prototype system, defect diagnosis and the decision-making process in construction are rendered easier, faster, and more cost effective in terms of maintenance assessment, defect diagnosis, and control of components of IBS building structures than conventional methods of construction. It also helps reduce the risk of defects in the design, such as the design calculation error, to provide high-quality components for the IBS building structure to ensure a safe and healthy environment.

METHODOLOGY

Case studies were undertaken on eight IBS buildings to identify problems in their maintenance management, prevalent approaches to addressing these problems, the implementation of ICT, and the use of emerging technologies and the maintenance management system (MMS) to obtain information on process for maintenance identification, assessment, planning, and execution. Eight maintenance clients/contractors were selected based on major problems in using the conventional method (paper-based reports/unsystematic databases) for comparison to investigate maintenance management practices in each IBS building. There were 51 contractors for IBS building maintenance according to a classification of the Precast Concrete (PC) system, the highest number among IBS building maintenance projects in Malaysia according to the CIDB. Most used the conventional method and inadequately employed modern ICT tools (Nawi *et al.,* 2014b). This indicates that the use of ICT is remains limited for PC system classification in IBS building maintenance management in Malaysia. The recommended sample size for interviews to obtain satisfactory results is between six (Morse, 1994) and 25 (Polkinghorne, 1989; Cited in Creswell, 2007) subjects "who have all experienced the phenomenon" (Creswell, 2007, p. 61); hence, eight key professionals working in IBS building maintenance units were interviewed for this study.

The synthesis of good practices for maintenance operations in the BIM-based CMMS Expert was based on the findings of the interviews and case studies. A total of 73.5% of IBS building maintenance in Malaysia features the use of the conventional method (Ismail *et al.,* 2016). The synthesis of good practices also features a cross-case analysis grouped into five "embedded units of analysis:" maintenance management problems, approaches to address these problems, ICT implementation, use of emerging technologies, and the proposed maintenance management system. This paper is part of a larger research project, and only introduces and discusses the framework of the proposed system in the following sections.

Synthesis of Good Practices

Table 1 below represents solutions suggested based on the case studies to improve current practices in maintenance management by implementing three approaches to the PC building. The analysis of Cases A, B, C, D, F, G, and H suggests improving the transfer of knowledge of defect diagnosis by combining the current system with related software technologies, such as CMMS and CAD. The problem of knowledge transfer in defect diagnosis also affects other PC buildings, and its significance is clear. Maintenance contractors have inadequate knowledge to handle the problem of defects, and struggle to gather accurate information records for inspection and planning. Another suggestion by clients/contractors was to use the transfer of knowledge to improve the quality of maintenance of structures and facilities in PC buildings (Cases A, B, D, F, G, and H). All related cases faced problems with the quality of knowledge management, which are associated to the defect repetition for handling the defect of structures and facilities with IBS score usage about 70% on its structure development of PC building.

Table 1: Proposed solutions from case studies

No.	Suggested Solutions	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
1	Provide more transfer of knowledge in defect diagnosis	/	/	/	/		/	/	/
2	Improve the maintenance quality in maintenance execution	/	/		/		/	/	/
3	Implementation of emerging technology (BIM) (efficient control of building performance based design/ monitor the defect component operation in maintenance)	/	/	/	/	/	/	/	/

The analysis of Cases C, D, E, F, and G suggests efficient control of design based on building performance and monitoring the operation of defect diagnosis in maintenance through the implementation of an emerging technology (BIM) to PC building maintenance. Cases A, B, and H also point to the need to integrate the design/construction and database of maintenance to facilitate better decision support and coordination within and across multiple fields (e.g. civil, mechanical, and electrical) for the effective management of PC building maintenance. This suggested solution was ranked the most important solution in almost all case studies. The use of emerging technologies is also the poorest in terms of current practices. As the overall results indicate in Table 1, it is necessary to analyse the use of emerging technologies further. Therefore, a system featuring emerging technologies, defect diagnosis, and the decision-making process should be developed to improve the building structure and facility performance by effectively transferring knowledge related to the maintenance defects in components of the structure.

LESSONS

1. PC building maintenance and the application of diagnostic techniques should be attended to. Because of the repetition of defects in components of the structure and limited understanding of PC buildings, the approach taken to maintenance is important. The application of modern ICT tools, such as BIM, can help avoid or alleviate defects in critical structure.
2. Appropriate ICT tools should be selected in areas of assessment (diagnosis and decision-making process concerning the design specifications used and construction implemented) for PC buildings. High-rise structures should be prioritised for these types of PC buildings.
3. The deficiencies in knowledge of PC buildings affect the competence of maintenance staff in Malaysia. Future work should seek to guarantee their competence in cases of defect repetition.

Requirements for Integrating Maintenance Management System

There were many problems related to the conventional method in the maintenance management of PC building, such as defect repetition (leaking, jointing, and cracking) and a lack of competent contractors. The conventional method also led to inaccurate design and construction information, late updates to the required information, and lack of coordination and integration. The high quality of IBS buildings and the long lifespan of the services require efficient management to maintain the building structure and facility at the PC building. Therefore, it is important to transform the conventional process into computer-based systems to improve maintenance management processes for complex projects, especially in the post-occupancy period of a building. In the case studies, the maintenance clients/contractors revealed a number of shortcomings in the conventional method. The knowledge of defects in the building was inadequate to help the maintenance management staff to handle the data and diagnose defects. The record of information was also inaccurate and could not be used to assess the conditions of components and make relevant decisions. The repetition of defects was frequent in PC buildings. Maintenance inspection and assessment had been unable to address defects in the buildings' structure in particular locations owing to a lack of knowledge transfer among members of maintenance management departments. Furthermore, incompetent contractor caused maintenance faults to increase.

In this study, a system is proposed to address the maintenance management problems in PC buildings, which are as follows:

a) defect repetition due to the failure to identify reasons for structure defects;
b) defect repetition (leaking, jointing, and cracking) due to design defects; and
c) incompetent contractors owing to a lack of knowledge of materials, methods, and design of structural repairs.

The processes consisted of: (1) Defect Report and Assessment; (2) Defect Diagnosis; (3) Defect Control, and (4) Report Protection, and are shown in Figure 1. Improvements to the maintenance management process in this system are as follows:

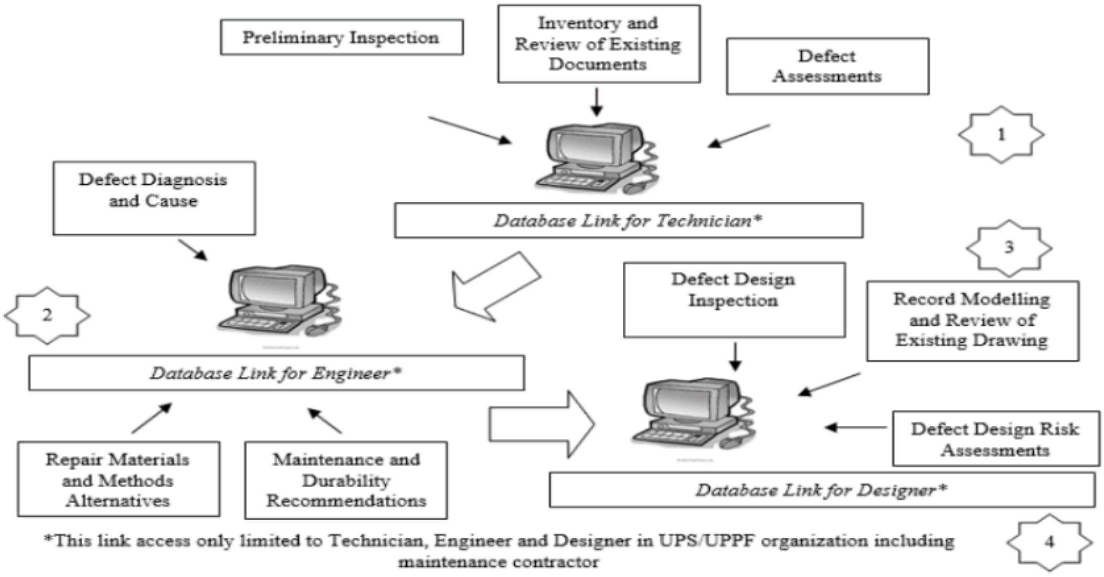

Figure 1: Configuration of improvements to maintenance management processes

1. Defect Report and Assessment: In report form, the user can enter data on the given structure and type of facility, and defect description, location, and visual inspection. The aspect of building can be classified as ‘structures’, ‘finishes’, ‘mechanical’, and ‘electrical’ in the system.
2. Defect Diagnosis: The system is considered a decision-making tool, and a comprehensive computerised expert system that provides recommendations on the components of PC structures. This defect diagnosis process is used to allow the user to select from among three knowledge bases—leaking, jointing, and cracking in concrete, including the selection of appropriate construction design or materials and recommended methods for repair. Engineers are expected to use this diagnostic to identify defects and determine their causes.
3. Defect Control: The BIM database is developed to provide technological transfer of knowledge from specialists to other practitioners, and vice versa, and provides a common forum for communication between designers and engineers. Therefore, it is a useful guide to everyone dealing with defects in components of PC structures. It is an excellent first-hand reference for a wide range of risks of defects in structural design and can facilitate accurate analysis using a design condition index coupled with an independent computerised expert system.
4. Report Protection: Access to all information in the maintenance management database is restricted because it includes personnel files, and documentation for the design, construction, and maintenance phases of the building.

Proposed Maintenance Management Processes

From the findings of the case studies, the process of maintenance management is maintenance identification (for defect report and assessment), defect and cause analysis (for defect diagnosis), and risk-level analysis (for defect control). These are the main stages in managing maintenance for PC buildings. The defect report and assessment are the initial process where a technician identifies defective components in the building. The defect inspection is then undertaken to assess the defect on site, and this information is entered in the system. The database of the system is linked with the three software, namely, the CMMS, Expert System, and BIM model. Knowledge transfer can then be used through this system when knowledge concerning the history of defect in a given component is provided to the engineer in the same organisation from the defect report and assessment. The engineer is assigned to screen each defect component for diagnosis to analyse the cause and reason for the defect. The expert system can be used to examine symptoms of the defect in each component based on knowledge from the literature, codes of practice, manuals, textbooks, technical reports, journals and conference proceedings, civil work reports, and experienced PC specialists.

This process of diagnosis consists of three knowledge bases, each of which contains information on the various features of defects in PC structures (e.g. shape, pattern, density, and location). The knowledge needed for diagnosing defects in the PC building is formulated as production rules (IF … THEN) and procedures and are incorporated into the knowledge base. These are typical forms of code in conventional programming languages. The entry type procedure of the knowledge base uses syntax similar to the Visual Basic programming language within the body of the procedure. Knowledge of defect diagnosis in the Expert System is then transferred to the designer in the BIM model for investigating causes of the design defect and reasons for it, and even to classify the level of risk posed by it. Finally, knowledge of the design defect based on specifications of the materials and visual information of the BIM model is transferred back to the engineer for work planning and maintenance execution. The knowledge transfer in this system improves the defect diagnosis and decision-making processes for critical defects.

System Architecture

The system architecture focuses on collecting structural and facility-related defect information for defect assessment, diagnosis, and control as well as an analysis of the data for execution reference in PC building maintenance. Such devices as laptops enable staff to compare and adapt the data at any facility using the staff report recorded in the prototype system's user interface (MS Visual Basic.NET). The staff can thus capture knowledge of the structure and defects in the facility, update details, and record the relevant aspect of defect attribution in the electronic form of the prototype. This knowledge is stored in a computer database centrally (MS Access) linked to the technician, engineer, and designer at the maintenance organisation for further processing. Information on the defect is assessed using the maintenance condition index to consider the given condition of the structure and its components, analysed for maintenance defect diagnosis using the decision-making process, and assessed using the design condition index to reduce the risk of design defects at the site. The specific maintenance workflow is illustrated in Figure 3. The 'CMMS Expert using BIM' can be divided into three components, BIM, CMMS, and Expert System. Each component plays a different role in the prototype system. BIM technology enables the analysis of defects in components of the concrete structure by comparing them and can generate a 3D model in the BIM database, whereas the CMMS stores the defect report and assessment. The Expert System contains knowledge of defect diagnosis, and the selection of a durable replacement design and material or the proper rehabilitation method for the system.

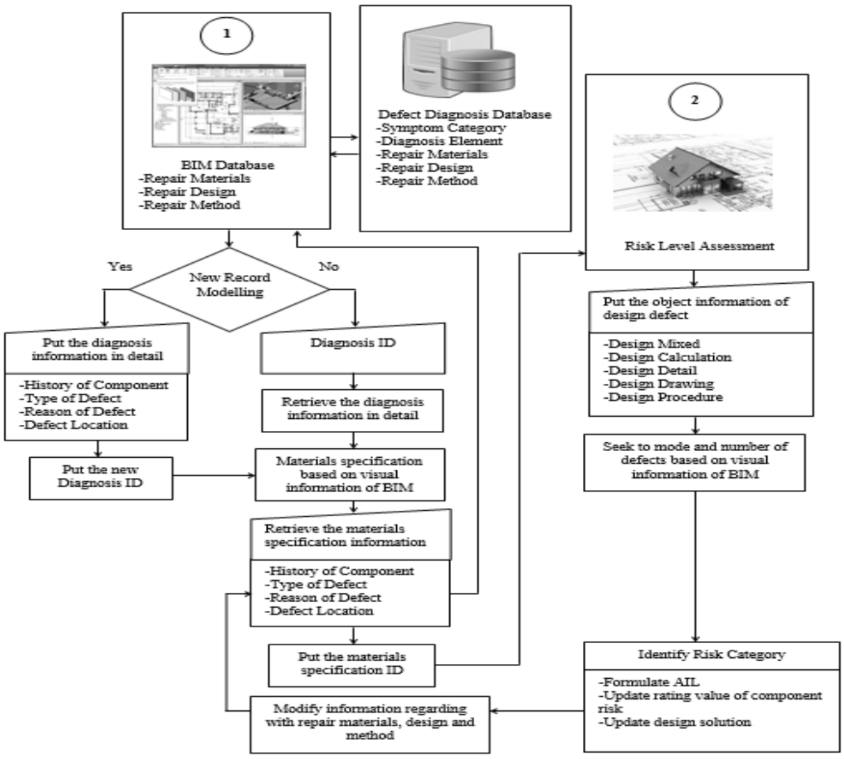

Figure 3: Defect maintenance process using CMMS, Expert System, and BIM

DISCUSSION

The prototype system was frequently tested by running it until critical problems had been fixed and the staff were confident in their ability to understand its functional requirements. The aim of testing the prototype system was to form several phases of the current value chain model (AS-IS) and construct a modified value chain model (TO-BE) with improvements to the prototype system (Yunus *et al.,* 2010). It provided the available structured system tools within an organisational context and a process modelling technique as the final refinement to install a system for application to maintenance management practices in IBS buildings.

CONCLUSIONS

Building a BIM-based CMMS Expert in an integrated manner is a vital task of IBS building maintenance. The framework proposed here helps engineers and researchers improve their knowledge of diagnoses of defects in components of IBS building to reduce risks of design defects throughout the building's lifetime. The use of technology to support maintenance processes and activities can have a positive impact on the delivery of service. Several systems have been developed to facilitate decision making support in IBS building maintenance. However, efficient practice requires a system that can handle decision making support in the context of diagnosis in an effective way. The proposed BIM-based CMMS Expert facilities can enhance decision making support in defect diagnosis.

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